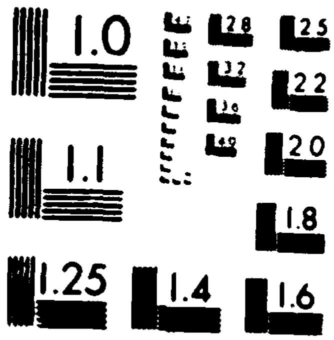
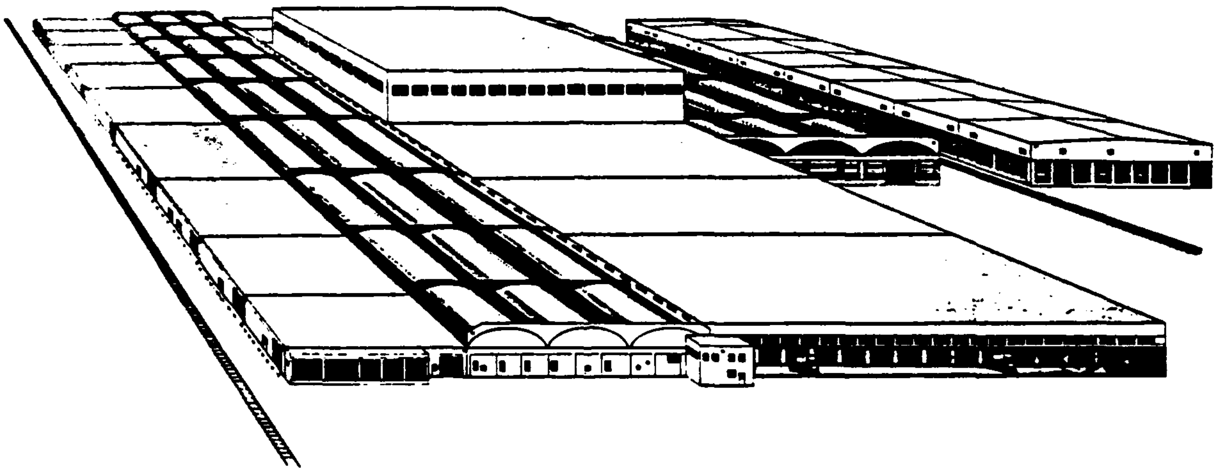
AD-A198 104 SIMULATING A STORAGE AND RETRIEVAL SYSTEM INTERFACED WITH AN AUTOMATIC GUIDED VEHICLE SYSTEM(U) DEFENSE CONSTRUCTION SUPPLY CENTER COLUMBUS OH J A CRUM 1/1

UNCLASSIFIED 30 JUN 88 F/G 15/5 NL



1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

SIMULATING A STORAGE & RETRIEVAL SYSTEM INTERFACED WITH AN AUTOMATIC GUIDED VEHICLE SYSTEM



PREPARED BY: JOSEPH A. CRUM

OPERATIONS RESEARCH AND
ECONOMIC ANALYSIS OFFICE

(DEFENSE CONTRUCTION SUPPLY CENTER)

30 JUNE 88

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release, distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Defense Construction Supply Center

6b. OFFICE SYMBOL *(If applicable)*: DCSC-LO

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS *(City, State, and ZIP Code)*: 3990 E. BROAD STREET, COLUMBUS, OH 43216-5000

7b. ADDRESS *(City, State, and ZIP Code)*:

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL *(If applicable)*:

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State, and ZIP Code)*:

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11. TITLE *(Include Security Classification)*: Simulating a Storage and Retrieval System Interfaced with an Automatic Guided Vehicle System

12. PERSONAL AUTHOR(S): Joseph A. Crum

13a. TYPE OF REPORT:

13b. TIME COVERED: FROM ________ TO ________

14. DATE OF REPORT *(Year, Month, Day)*: 30 Jun 88

15. PAGE COUNT: 84

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*: Simulating; Warehouse; Storage and Retrieval; Automatic Guided Vehicles

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The warehouse simulation model was developed to assist a depot modernization task force in designing one component of a five year modernization plan. The task required that separate models for a storage and retrieval system and a transport system be written and integrated. The model for the storage and retrieval system was written in FORTRAN and simulates an orderpicking operation with several unique features including sequencing and batching of orders, variation in the stacking height for each storage level, and movement of S/R machines between aisles.

The AGV transport system model was generated using both FORTRAN functions and SLAM network statements provided in the Material Handling (MH) extension package. The integration of the AGV transport system model and the S/R system model utilized the SLAM simulation language.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Joseph A. Crum

22b. TELEPHONE *(Include Area Code)*: (AV)850-2209

22c. OFFICE SYMBOL: DCSC-LO

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

ABSTRACT

The purpose of this project was to design and simulate a high-rise pallet facility for a defense depot. The high-rise storage structure utilizes Storage and Retrieval (S&R) machines for performing picking and stowing operations. Automatic Guided Vehicles (AGVs) are used for transporting loads to and from the storage structure.

A simulation model was developed to mimic the dynamic elements of both the S&R and AGV systems. The model was used to evaluate the size and scope of the system, how operating policies would affect performance, trouble areas or possible bottlenecks and the utilization of the equipment.

The task required that separate models for the storage and retrieval system and the transport system be written and integrated. The model for the storage & retrieval system was written in FORTRAN and simulates an orderpicking operation. Several unique features were incorporated, including sequencing and batching of orders, variation in the stacking height for each storage level, and movement of S&R machines. S&R machines were allowed to move freely within their assigned bays although only one S&R machine was permitted in an aisle at a time.

An AGV transport system model was generated using both FORTRAN functions and SLAM network statements provided in the Material Handling (MH) extension package. The control points, segments of the guidepath, and the AGV specifications were all input as resource blocks. Logic rules were available through the MH package to handle contentions at intersections, routing of vehicles, directional characteristics of the track segments, job requests, vehicle requests, and idle vehicle disposition. The integration of the AGV transport system model and the S&R system model required the use of SLAM II.

The client's overriding concern was to provide customer service. Currently, this concern translates into an operating policy in which the S&R system fills all picking orders before performing any stows. Meanwhile, the AGV system can pick up material for storage whenever it arrives at the receiving terminal of the warehouse. The simulation of this policy, described in Case 1, indicated that both systems would experience total 'lockup' and fail as all input and output queues became saturated and movement was impossible.

A suggested change to the system was the addition of a loop onto which loaded and blocked AGVs were diverted (Case 2). Although the system modeled operated more smoothly, the S&R system still experienced excessive blockage and the AGVs spent a large percentage of their operating time travelling the loop. By preventing the AGVs from picking up material to be stowed until eleven o'clock (Case 3), the effective utilization of the S&R equipment was increased to more than seventy five percent. One hundred percent utilization can never be achieved because of the transient nature of the system. Higher utilization may be achieved by scheduling multiple or split shifts.

The simulation model allows the user to make some modifications in the design configuration, material handling equipment specifications, and operating policies. Major changes require the knowledge and assistance of a programmer who is familiar with SLAM. An animation package would enhance the client's understanding of the model and assist in 'seeing' potential bottlenecks or hangups in the current design.

JOSEPH A CRUM is an Industrial Engineer in the Operations Research and Economic Analysis Office at the Defense Construction Supply Center (DCSC) in Columbus, Ohio. Joe received both his B.S. and M.S. Degrees in Industrial and Systems Engineering from Ohio University in 1981 and 1987 respectively. Joe joined DCSC in June, 1986, prior to publishing his thesis. Previously, Joe has been employeed by Columbia Gas of West Virginia as an Operations Engineer. In 1981, Joe served as chapter president for the American Institute of Industrial Engineers.

TABLE OF CONTENTS

APPENDIXES (Available Upon Request From Author)

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Background

The purpose of this project is to design and simulate a high-rise pallet facility for a defense depot. The high-rise storage structure utilizes Storage and Retrieval (S/R) machines for performing picking and stowing operations. Automatic Guided Vehicles (AGVs) will be used for transporting loads to and from the storage structure.

A simulation model will be developed to mimic the dynamic elements of both the S/R and AGV systems. The simulation model will be used to evaluate:

1. the size and scope of the system

2. how operating policies will perform

3. trouble areas or possible bottlenecks

4. the utilization of the equipment

Problem and Objective

A high-rise pallet facility is considered the cornerstone project for the modernization efforts of the defense depot. The high-rise structure will allow faster moving palletized material from 515,235 square feet of heated and lighted conventional warehouse space to be consolidated in a smaller area. A projected annual savings of 45.8 Million British Thermal Units (BTUs) or $257,508.00, will be realized by eliminating the heating and lighting requirements of the four conventional warehouses. The new warehouse will also accommodate the projected twenty seven percent increase in Stock Keeping Units (SKU's) over the next five years.

The objectives are to:

1. develop a preliminary layout for the storage structure

2. select the appropriate operating policies for the S/R machines and the AGV system

3. develop a simulation model to check the system design

The simulation model will allow the user to make some modifications in the design configuration, material handling equipment specifications, and operating policies. Major changes require the knowledge and assistance of a programmer who is familiar with SLAM.

CHAPTER 2

LITERATURE

Material Handling in Computer Integrated Manufacturing

The American economy has been changed by the evolution of global markets and foreign competition. The shift of our economy has been from manufacturing to service. These trends have resulted in the slowdown of growth of the Gross National Product (GNP) and the deterioration of several major industries. In order for the United States to regain some of these markets, Spencer(38), recommends that U.S. industries turn to automation and computer integrated manufacturing (CIM). Spencer believes these steps must be taken now to insure a future for U.S. industries in the international market.

Groover and Wiginton (15) indicate that there are two basic components to a computer integrated manufacturing system. They are:

1) factory information and communications

2) material handling.

Factory information and communications connect procurement, order entry, planning, scheduling, inventory control, quality control, and shipping together by means of a communications network. The network makes use of a common data base shared by all the functions.

The second component, material handling, is concerned with the movement, storage and control of materials. The transportation system design must handle peak demands in order to prevent in process material delays and balance transportation and storage system throughput capacities with common interfaces, such as pickup/dropoff (P/D) stations. The material handling equipment must be capable of dealing with product size and weight variations and be flexible enough to accommodate alternate routing throughout the facility.

This investigation will concentrate on two types of material handling systems, the Automatic Storage and Retrieval System (AS/RS) interfaced to an Automatic Guided Vehicle System (AGVS).

Automatic Storage and Retrieval Systems

Material Handling Engineering (MHE) (23) describes the AS/RS as the technology that takes best advantage of the cube and height of a storage system while offering security and inventory control. MHE also states that the AS/RS is the most efficient and fastest manual batch picking operation, the best in-process buffer, the most precise and dependable controlled inventory system, and the system that is most responsive to just-in-time (JIT) material delivery requirements.

According to the Handbook of Industrial Engineering (35), the AS/RS consists of storage racks, storage/retrieval (S/R) machines, Input/Output (I/O) or Pick-up/Deposit (P/D) stations, transportation devices, and controls.

There are three basic types of S/R systems described by Rygh (34). The first is the unit load system. This system handles inventories in unit loads which are usually palletized or placed on "slave pallets". The second is the order picking system, also known as the person-on-board system. This system is used for storing and retrieving materials of less than unit load quantities. The final S/R type is the work-in-process system. This system is used in CIM as a buffer storage between two production processes with different material throughput rates.

Rygh (34) provided the following list of benefits from using a AS/RS system:

1) better space utilization

2) less direct and indirect labor

3) reduced inventories

4) less energy consumption

5) reduced pilferage

6) less product damage

7) improved working conditions

8) easier housekeeping

9) less equipment damage

10) improved customer service

11) better management control.

Automatic Guided Vehicular System

Groover and Wiginton (15) describe the AGVS as the arteries of an integrated material handling system. AGV's are independently operated, battery-powered vehicles that follow pathways defined in the warehouse floor. The pathways are defined by means of a guided wire imbedded in the floor or a chemical paint stripe marked on the surface of the floor. Sensors on-board the vehicles track the pathways and make deliveries between various stations on the track. AGV's are capable of variable routings, can carry a variety of loads by using standard pallets to hold the loads and can be operated under computer control.

According to Rygh (34), AGV's fall into one of five categories; each is designed to accommodate different applications.

1. Unit load vehicles. These vehicles are designed to transport one or more unit loads at a time and can be equipped with various material handling devices for automatic pick up and discharge of the load.

2. Tugger or tow vehicles. These vehicles are designed to pull a cart or a train of carts and can automatically hitch or release the trailers.

3. Pallet movers. These vehicles are low lift carriers resembling walkie pallet trucks. Loading and unloading may be accomplished manually or automatically.

4. Picking or stacking vehicles. These vehicles are equipped with forks to pick up loads from the floor and deposit the load at some elevated position.

5. Manufacturing vehicles. These vehicles are used for transporting unique loads in a work-in-process environment.

Some of the benefits of AGV Systems given by Norman (28) include:

1) automatic interfacing

2) flexible system capacity

3) tighter material control

4) increased productivity

4) efficient use of floor space

5) easily adapted to automation

6) ease of installation.

Storage System and Policies

The storage facility for an AS/RS is generally one of two types: free standing structure or the rack supported structure. The free standing structure consist of racks which are installed inside of a building and is considered to be mobile. The rack supported structure is fixed since the racks are an integral part of the building structural support.

The rack supported structure is not only the cheapest to build, but it also offers other advantages. For example, the internal revenue service treats racks as equipment rather than as a building for depreciation purposes. Equipment can be depreciated over a shorter life than buildings and it may also receives special Investment Tax Credits (ITC) and sales exemptions. Rygh (34) estimates that rack supported structures are twenty (20) percent less expensive than the buildings and equipment with free standing racks. Under the new tax laws, according to Schwind (36), the rack supported structure will not qualify for ITC.

Many factors in the storage matrix of an AS/RS can be varied to speed up the throughput and to maximize orderpicking productivity. The percentage and position of dedicated versus non-dedicated storage locations, the location of fast-moving versus slow-moving items, and the selection density of the items affect the throughput.

Graves, Hausman, and Schwarz (14) examined three storage assignment rules for unit load S/R system. The first is known as Random Storage Assignment (RAN). In this storage system all items have an equal chance of being stored in each of the storage locations. The second is called the Class Based storage system. This system separates the items and the locations of the storage racks into a small number (2 or 3) of classes. The most popular items are placed in storage class closest to the P/D station and the items are then stored randomly within a class. Less popular items are likewise stored at greater distances from the P/D station. The last storage assignment rule to be examined is the Full turnover-based storage system (FULL). This rule results in a dedicated storage system which assigns a storage location to an item based on its turnover rate. The item with the highest turnover rate is assigned to the location closest to the P/D station.

Table 1 contains the results of study done by Graves, Hausman, and Schwarz (14). They simulated the operation of a AS/RS system using the above rules and reported the percentage improvements of the latter two types of storage assignments over random storage. The performance of the assignment rules depend on the characteristics of the inventory; a 20/60 ABC curve means that 20% of the inventory items account for 60% of the total demand.

TABLE 1

RESULTS OF A STORAGE ASSIGNMENT STUDY

ABC Curve	% Improvement over Random Storage		
	Two Class	Three Class	Full Turnover
20 / 60	18.1	22.4%	26.3
20 / 70	25.5	31.4	36.9
20 / 80	35.9	43.7	50.8
20 / 90	52.9	62.5	70.6

Their study indicated that a 2-class system requires a 2% to 3% increase in the number of storage rack openings compared to a random storage system. For a 3-class system requires a 4% to 5% increase in storage rack openings. Their calculations are based on the 95% confidence interval. That is, when an item is to be stored, a location in the proper class will not be availabe for about five percent of the storage request.

Davies, Gabbard, and Reinholdt (7), evaluated four commonly used space assignment methods for order picking systems.

1. alphanumeric
2. fast and other
3. frequency
4. Seletion Density Factor (SDF)

In the alphanumeric scheme, all items are assigned a storage location in their alphanumeric sequence. The second is placement of the items in two classes 'fast and other'. The most frequently selected items are placed closest to the P/D station. Items within each class are stored in a alphanumeric sequence. The third placement method is placement by frequency. The items are stored by frequency of demand or 'number of hits'. This is the same approach used in the FULL turnover-over based storage method for unit load S/R systems, except that multiple unit loads of an item may be stored rather than a single load for each item. The fourth type of placement is the Selection Density Factor. For this storage method, the number of selections made per year for an item is divided by the required storage volume. This value is referred to as the SDF value . Items with the highest SDF values are placed closest to the P/D station.

In the case study reported by Davies, et al. (7), the SDF placement method was the best of the four storage strategies examined. The SDF placement method reduced labor requirements and storage requirements. The average travel distance between the P/D station and an item was also reduced by the largest factor. Other benefits of SDF assignment include a reduction in material handling effort for restocking purposes, improvement of supervision because the workers were confined to a smaller working area. Picking accuracy also improved because similar items, such as different types of safety glasses, resistors or fuses, were not grouped alphanumerically.

In another case study conducted by Hamada (16), the benefits of storing fractional unit loads of multi-packaged items on pallets were considered. If the order for a fractional load matches one of the stored loads a manual pick operation can be avoided. Fractional loads do not maximize storage space utilization. A 11% improvement in the throughput of the AS/RS was achieved with only a 0.8% sacrifice in storage capacity. Hamada noted that this improvement was only realized because the commodities had a comparatively small number of parts or containers per pallet.

In a article from Modern Material Handling (MMH) (29), another potential improvement for a AS/RS storage system is mentioned. For a product mix that varies in height, consideration should be given to varying the heights of openings within the storage rack. The author states that this arrangement will provide better utilization of the storage cube if many items can be stored in each height category.

Finally, Heneveld (10) of the Ford Motor Company suggests that consideration must be given to the timeliness of accessing materials in a work-in-process environment. In the case of a S/R machine failure, or backlog on a particular aisle, he suggests storing identical commodities in different aisles. Shell Chemical of Belpre, Ohio also uses this concept to speed up the loading of trucks for shipping.

S/R Machine and Operating Policies

The S/R machine stores and retrieves loads from the storage structure. The typical S/R machine operates on a floor mounted rail and is guided at the top. The power supply is sometimes provided by the upper rail. Other S/R machines are battery powered and may move between aisles under their own power. If the S/R machine is not equipped with a battery pack, transfer mechanisms are available to make interaisle movements.

The S/R machine operates in three directions. In the horizontal direction, the S/R machine moves back and forth within the aisle. In the vertical direction, a hoist is used to raise and lower the carriage. In the lateral direction a shuttle drive transfers the loads from the S/R machine to a storage location on either side of the aisle. Most S/R machines can operate both vertically and horizontally simultaneously. To take advantage of this capability, AS/RS systems are typically designed to be "square in time".

The S/R machine comes in a wide variety of sizes and configurations because it's design is a function of the loads it carries and the tasks it performs. Savendy (35) describes three sizes of S/R machines. The "maxiload" machine is used for pallet load systems and handles loads of 1500 pounds or more. The "miniload" machine is smaller and handles loads ranging up to 500 pounds. The "microload machine" must be a "driverless" system and is used for loads less than 80 pounds.

There are two types of S/R order picking systems. The first is "in-aisle" orderpicking. The operator picks from pallets, shelves, bins, or drawers within the storage structure. The loads are then carried to the end of the aisle for dispatching. The second type is "out-of-aisle" orderpicking. The unit loads, bins or totes are automatically retrieved from storage, and brought to the end of the aisle.

For the out-of-aisle order picking system two different scenarios are used for storing and retrieving unit loads. The first is referred to as the 'single address' system or the 'noninterleaving' (NIL) policy. In this case, the S/R machine performs either a storage operation or a retrieval operation, but not both, before returnig to the P/D station. The second, is referred to as the 'dual address' system, also known as a 'mandatory interleaving' (MIL) policy. In this case, the S/R machine stores one unit and then retreives another, before returning to the P/D station. Throughput is increased by performing 'dual transactions'.

The throughput for dual transactions can be further increased by carefully selecting the retrieval request. On a first come first serve (MIL/FCFS) basis the retrieval waiting the longest amount of time is selected. Under the queue selection rule (MIL/Q=K), the next K retrieval locations are examined to see which is closest to the next storage transaction. The closest is selected to reduce intertransaction travel time. Nearly, all of the benfits of the queue selection rule can be obtained by considering only the first few request in the retrieval queue.

Graves, Hausman, and Schwarz (14) computed the benefits made for several storage policies, S/R policies, and queue selection policies. The improvements for a 20/60 inventory over RAN/NIL/FCFS policy is presented in Table 2.

TABLE 2

BENEFITS OF VARIOUS STORAGE AND RETRIEVAL POLICIES

Policy Considered	% Improvement over RAN/NIL/FCFS
1) RAN/NIL/FCFS	0
2) FULL/NIL/FCFS	26.4
3) C2/NIL/FCFS	18.1
4) C3/NIL/FCFS	22.4
5) RAN/MIL/FCFS	32.5
6) FULL/MIL/FCFS	46.4
7) C2/MIL/FCFS	42.4
8) C3/MIL/FCFS	44.4
9) C2/MIL/Q=2	44.4
Q = 5	45.6
Q = infinity	46.5
10) C3/MIL/Q=2	46.1
Q = infinity	50.1

For in-aisle orderpicking, there are three methods listed in the MMH-986 Warehousing Guidebook (40). Sequential orderpicking is where a manaboard operator takes each order and moves through the warehouse making selections. After completing an order, the operator drops it off at the closest P/D station for delivery to packing or shipping. For batch orderpicking, a manaboard operator fills multiple orders at the same time. In zone picking the operator is assigned a specific portion of the storage area for filling orders. The manaboard operator then completes all orders within that zone. Both batch and zone picking reduce the travel time but a sorting operation must be done after picking operations.

Graphs of the interrelationships between the pick container size, travel time, the number of required replenishments, and the quantity stored at the pick location are given in Figure 1. An increase in the quantities stored results in increases in the picking area size and travel time to perform a picking cycle. The number of replenishments decrease as the quantity stored increases.

Lotting of items can also have an effect on the number of unit loads that are required. Based on the assumptions that the cube of the item is known beforehand, and that the shape will not have an impact on the lotting of items, Barrett (3) presents four approaches for lotting items. In the first method items can be lotted by random assignment (RAN). In this case, each item is scanned on a first in first out (FIFO) basis to see if it will fit on the picking lot being formed. The second method, volume assignment (VOL), can reduce the number of lots by combining the smaller items into a single lot. The third approach uses a modified random (MRAN) assignment. In this case, if the next item being considered will not fit, it is skipped, and the remaining items in the queue are scanned in sequence to see if any will fit in the lot being formed. The fourth method (LOAD) is to sort the items in decreasing size, and then combined in the same manner as MRAN.

Barrett (3) discusses other ways to reduce order picking time. One of his recommendations is to pick in a double pass sweep, that is, the operator starts at the P/D station, works from left to right along the lower half of the rack, and then returns from right to left along the top half of the rack. This heuristic reduces the travel time and is much easier to implement than the shortest path algorithm which is used for transportation problems.

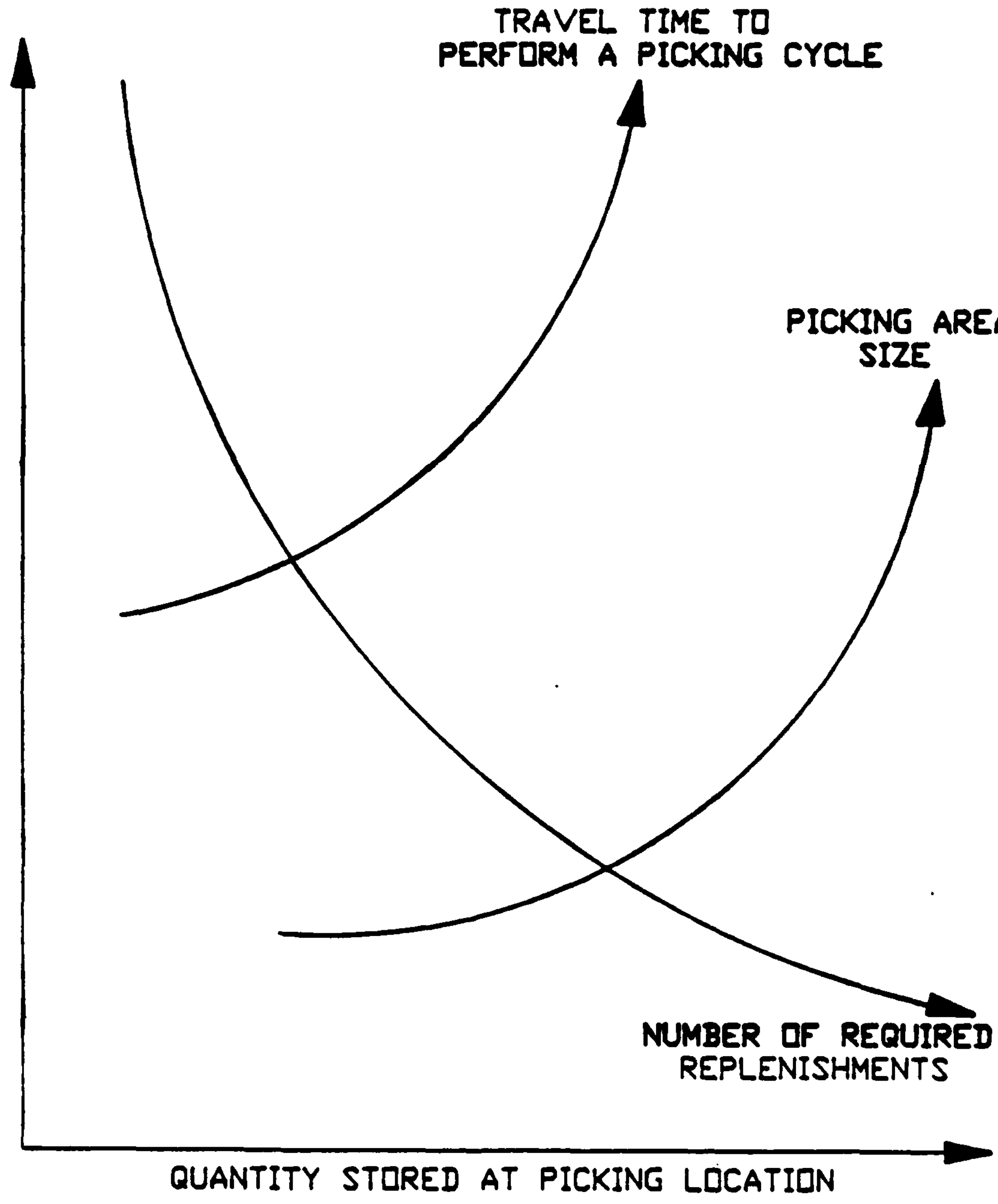


FIGURE 1 ANALYZING ORDER-PICKING OPERATIONS

Transportation Devices

There are many types of transport devices which can be used with the AS/RS: forklifts, roller or chain conveyors, overhead power and free conveyors, in-floor towlines, shuttle trolleys, and guided vehicles. The choice again, depends on the system's throughput requirements, the type of load to be handled, and the degree of interaction with shipping, receiving, and other warehouse operations. Automatic guided vehicles (AGV) will be the transport system covered here.

AGV's are often referred to as the arteries of the material handling system. AGV's are independently operated, battery-powered vehicles that follow specific pathways. The pathways are defined by means of a guided wire imbedded in the floor or a chemical paint stripe marked on the surface of the floor. Sensors on-board the vehicles track the pathways and make deliveries between various stations on the track. AGV's are capable of variable routings; they can carry a variety of loads by using standard pallets to hold the loads; and they can be operated under computer control.

AGV's may operate under three levels of systems management control. Norman (28) discusses each.

1. On-board dispatching is performed by an operator who enters the appropiate codes on the vehicle to dispatch it to one or more stations.

2. Remote terminal dispatching is also performed by an operator who enters the appropriate codes from a remote terminal to send the vehicle to one or more stations.

3. Central computer dispatching is performed by a dedicated computer or by a computer which supports other components of production (e.g. AS/RS).

Norman (28) also discusses other operating strategies, such as which AGV should be selected if more than one AGV is available to transport a request. Norman lists five possible rules:

1) Select the vehicle randomly from the set of available vehicles.

2) Select the vehicle which has the shortest travel time to the pickup station.

3) Select the vehicle which has the longest travel to the pickup station.

4) Select the vehicle that has been idle the longest since its last task.

5) Select the least utilized vehicle.

Norman (28) discusses another issue that deals with selecting a task. If more than one task is waiting when a vehicle becomes available, Norman lists six different rules that can be used:

1) Select the task randomly.

2) Select the task that is waiting in the station that has the maximum on-hand outgoing queue size.

3) Select the task that is waiting in the station which is the closest to the vehicle.

4) Select the task that is waiting in the station which is the farthest from the vehicle.

5) Select the task that is waiting in the station that has the smallest remaining outgoing queue capacity.

6) Select the task that has been waiting the longest from a subset of waiting tasks. This subset allows only one task from each station to be waiting.

AGV's are often called the 'backbone of the material handling system' because they offer the flexibiity to move variable products over different routes. In Burlington Industries MMH (1) new automated textile plant, AGVS and an advanced computer control system have linked handling and manufacturing in what must be the most automated textile plant in the world. More than 2,000 I/O stations forms the interface betweeen processing machines, two AS/RS and a nine-dock shipping area. Four types of trailers are used with the guided vehicles; most loading and unloading operations are automatic.

Mechanical Interfacing of the Various Systems

The term 'mechanical interfacing' refers to the capability to transfer loads back and forth between various systems in the warehouse. The most promising scheme for achieving load transfers between the various systems in the warehouse makes use of standard-sized containers and/or pallets. Some requirements of the transfer mechanism must be accurate, reliable and sufficiently fast acting so that it does not cause a bottleneck in a smooth flowing system. The accuracy is required for aligning the transfer mechanism between the two systems to prevent jamming. This level of accuracy may be achieved by using tapered pins or other alignment devices to locate the material handling carrier(e.g. the AGV and AS/RS) at the transfer station.

Groover and Wiginton (15) have listed some common transfer mechanisms that are designed for loading and unloading between material handling systems. They are:

1) lift-and-carry devices
2) push-pull devices
3) AGV's with powered rollers or powered belts
4) AGV's with lift-and-lower platforms
5) deflectors

The AGVs may operate at end-of-aisle interfaced with P&D stations or enter the first level of AS/RS rack and be unloaded directly by the S/R machine. Other techniques for feeding an AS/RS are discussed in MHE (23). They include the use of self-powered monorails and overhead cranes.

The AS/RS can be designed for specific operations and orderpicking requirements by varying the location of both the input (I) station and the output (O) station. Bozer and White (4) conducted an analytical study that showed the effects of locating the I&O stations at different positions. The comparisons are made with respect to the conventional method of locating both the I&O station at the lower left hand corner of the storage matrix. The results of their study are shown in Table 3.

TABLE 3

EFFECTS OF LOCATING THE I&O STATIONS AT DIFFERENT POSITIONS

I&O Locations	% Improvement
1) opposite ends of the aisle	10.5
2) the same end of the aisle but at different elevations	18.3
3) the same elevation, but at the midpoint in the aisle	39.7
4) elevated at the end of the aisle.	16.2

The Controls

The control techniques used in a AS/RS determine how the system will operate. For high volume light variety conditions, White (45) suggest using 'hard or rigid automation', and for low volume and high variety conditions, he recommends using 'soft or flexible automation'.

In AS/RS the unit load system is a excellent candidate for 'hard or rigid automation'. As an illustration, each S/R machine has its own on-board microprocessor which controls the individual machine. The I/O stations and the transport devices are controlled by one or more microprocessors. All of these processors communicate with one or more equipment controllers which in turn direct the movement of the equipment and provide system information. The equipment controller in turn, communicates with a the larger minicomputer which provides the overall AS/RS control. This computer may also perform tasks like inventory control, data collection, and networking control. In a CIM system this minicomputer is frequently linked to a larger computer which provides corporate infomrmation.

The order picking S/R system is less condusive to 'hard or rigid automation. Instead, 'soft or flexible automation' is often used. MMH-1986 Warehousing Guidebook (29) presents two examples of 'soft or flexible' automation in in-aisle S/R order picking systems. In the first example, the operator may use picking labels or a bar-code reader. The picking labels are affixed to the product as it is picked and the operator turns in the unuseable labels to indicate out-of-stock items. If a bar-code reader is used, a list of the picked items can be generated as the selection is made.

In the second example, all paperwork is eliminated. A lamp, counter-display, and a button are mounted at each picking location. The lamp lights up next to the items to be picked, and the display indicates the quantity required. The picker hits the button to inform the computer the pick has been made and the light is turned off.

SIMULATION

Today's advanced materials handling systems must interact with a variety of complex operations in ways that are not always intuitively obvious. The more complex a materials handling system is, the harder it is to predict how it will perform. One way to minimize the risk is to simulate the proposed system with a computer model that simulate the proposed system with a computer model that attempts to mimic the way a system will actually work. Ultimately the simulation model must answer the broad question of whether the system will operate as planned, and detailed questions about equipment utilization, and the effectiveness of component choices and operating strategies.

According to Modern Material Handling (MMH) (11), a computer simulation models can be used to:

1) establish the scope and size of a system

2) evaluate different hardware configurations and operating policies during the design stage

3) test and debug components during development

4) perform analyses of the system in operation

5) examine alternate operating strategies.

Unfortunately not all companies use simulation techniques. In a survey conducted by MMH (41), 700 companies responded to the question:

"Does your company use simulation analysis to check the feasibility of a proposed material handling system design?" Only 14% of the respondents answered positively. About 30% of the companies with annual sales between 125 million and 1 billion use simulation, and almost 50% of companies with more than 1 billion in sales used these modeling techniques.

Glenney and MacKulak (13) recommend that an automated warehouse simulation model should include the following components:

1) the human-factored work environment

2) the automation/computer controls

3) the islands of automation

4) the material handling systems.

Many simulation models have been prepared for the AS/RS system. Dangelmaier (8) used the computer simulation language SIMULAP to model the "front court area of a high-bay warehouse". Perry, Hoover, and Reeman (31) used the general purpose language Fortran because of its modelling flexibility and transferability to other systems. Bailey (2) used the Basic language and then interfaced the program with a Computer Aided Design (CAD) system. Grant and Wilson (12) used the Slam II simulation language because of its direct applications to material handling systems. The marketer of SLAM II, Pritsker and Associates, have just recently released two new modelling functions for material handling equipment. Both functions have direct applications to AGV and S/R systems. Norman (28) used SIMAN to simulate AGV Systems. SIMAN offers a modeling framework for materialing equipment, routing and scheduling.

CHAPTER 3

SYSTEM DESIGN

General Considerations

The simulation model was developed to answer the following questions:

1) What is the scope and size of the system?

2) Will the system operate as planned?

3) Are there bottlenecks in the system?

4) What percent of the time is the equipment utilized?

Programming Languages

According to Pritsker, A. B. and Pegden, C. D. (32), the following features should be considered when selecting a simulation language:

1) the ease of learning the language.

2) the ease of coding; including random sampling and numerical integration.

3) transferability of the language onto other computers.

4) the flexibility of the language in supporting other modeling concepts.

5) the ease of gathering statistics, allocating core memory, producing standard and user-tailored reports.

6) the ease of debugging and the reliability of the support systems, and the documentation.

7) the compliation and execution speed.

Only two simulation languages were available to the author: SIMSCRIPT and SLAM II. SLAM is the ancestor to the SIMAN simulation language. The author had been exposed to SIMAN simulation, and therefore SLAM II was chosen on its availability and the author's knowledge of a similar language.

SLAM II was developed by Pegden, C. D., and Pritsker, A. A., and is presently supported by Pritsker and Associates, Inc. of West Lafayette, Indiana. The source language was written in FORTRAN and is available for mainframes and microcomputers. SLAM II has been specifically designed for simulating manufacturing problems and recently extensions for material handling (MH) equipment have been added. The MH extensions are in a network form and represent S/R machines and AGVs.

SLAM was the first simulation language to provide all three modeling viewpoints in a single integrated framework. The three modeling viewpoints are network, discrete event, and continuous modeling and/or any combination of the three.

The network model consists of a set of interconnected symbols that depict the operation of the system. The node and branch symbols are used to represent the model and its routing and processing functions.

The flow of entities through a network is defined by the sequencing of the network input statements. If a node statement is followed by another node statement, an arrival to the first node is followed by an arrival to the second. Nonsequential routing of an entity is specified by referencing the label of the node to which a transfer is made. For example, balking an entity from a QUEUE node to a COLCT node is accomplished by including the label of the COLCT node in the QUEUE node statement. This feature is equivalent to a GOTO statement in FORTRAN.

In a discrete event orientation, the modeler defines the events and the potential changes to the system. The mathematical-logic associated with each event is coded in FORTRAN. SLAM provides a set of subroutines and functions that are commonly used to describe discrete events. These subprograms include: scheduling events, manipulating files, collecting statistics, and generating random samples. The random sample generator for SLAM II contains the exponential, uniform, Weibull, triangular, normal, lognormal, Erlang, gamma, beta, and Poisson distributions and the user can add routines for other distributions.

SLAM II controls the simulation in the executive control program by advancing time and initiating calls to the appropiate event subroutines. If any user written subprograms are included in a SLAM model, the dummy versions are replaced by linking the compiled user-written FORTRAN version with the compiled SLAM library. Thus, the modeler is relieved of the responsibility of sequencing the events in chronological order.

In the author's program, the network file is used to represent the physical configuration: storage structure, S/R machine, input and output stations, AGVs and track layout. The FORTRAN files are used to represent the operating policies: sequencing of orders, lotting, scheduling of S / R machines and AGVs, etc. The continuous orientation was not used in the author's model.

Some problems were encountered with the SLAM language as the model was being developed. First, the user written SELECT function NQS would not always return to the FORTRAN subroutine. In the case when entities were held in only one QUEUE node, the executive control program would default to the first available server. Thus, the user-written selection rule could not be used to schedule parallel servers. An error was detected if an attempt was made to override the system. When entities were held in two or more QUEUE nodes, control would be passed to user-written SELECT function. The SELECT function in turn, would pass back the activity number associated with the server selected. If no server could be selected, then a zero was returned.

Description of the S/R System

The material to be stored in the high-rise warehouse complex is classified as pallet rack type merchandise and is pack in single units weighing up to 1500 pounds, or mann dle packages weighing 70 pounds or less. The product mix includes general and industrial supplies as well as construction materials.

Standard-size pallets are to be used for making load transfers between the various systems. The standard pallet is 40 inches deep by 48 inches wide, with a maximum storage height of 60 inches. A maximum of three pallet loads of any one line item is stored in the racks. Any line item with a quantity in excess of three pallets is stored in the bulk warehouse which is outside the system.

In the pallet handling system, a stow transaction is defined as the movement of a palletized load from the receiving area into storage. A pick transaction is defined as the movement of a palletized load from a storage area to the shipping area. A transshipment, also referred to as a "walk-through" transaction, is the movement of a palletized load from the receiving area to the shipping area.

Material Release Orders (MROs) are authorizations to pick, release and ship material from storage. There are three types of MROs, each is color coded to indicate its priority. A "red" MRO has a priority of one; the material is to be picked, packed and shipped within one day to the customer. A "green" MRO has a priority of two and must be completed within two days. A "white" MRO has the lowest priority (a three), and warehouse workers have three days to pick the material.

The return of merchandise, the receipt of new material or the replenishment of a stock keeping unit (s.k.u) generates a stow transaction. A transshipment is a combination of both a pick and a stow transaction. A transshipment results when there is a backorder on the merchandise. To reduce the time delays to the customer, when an adequate quantity arrives, the item is taken directly to the shipping area.

The merchandise handled is rackable material with a fairly large cube. These items are either manhandle packages or single unit loads. Manhandle packages are carton items weighing seventy pounds or less. The average number of manhandle packages per pallet is nine. A single unit load is defined as an item weighing more than seventy pounds with only one package or container on a pallet. The maximum capacity of either the multipackage load or a single unit load is 1500 pounds. The S/R system is therefore both a orderpicking system and unit load system.

The standard transaction times for rackable order picking operations have been developed by the accounting office and are outlined in the work measurement standards. The standard pick transaction consists of a single order document issue. Each issue consists of one line item per document. The number of pieces picked per line item varies. The number of orders (customers) and line item issues (documents) processed during an order picking cycle have been sampled. See Figure 2A for an example.

A standard stow transaction consist of one line item per receipt document. The number of containers to be stored per line item varies. The number of line items processed during a stowing cycle has also been sampled. Refer to Figure 2B.

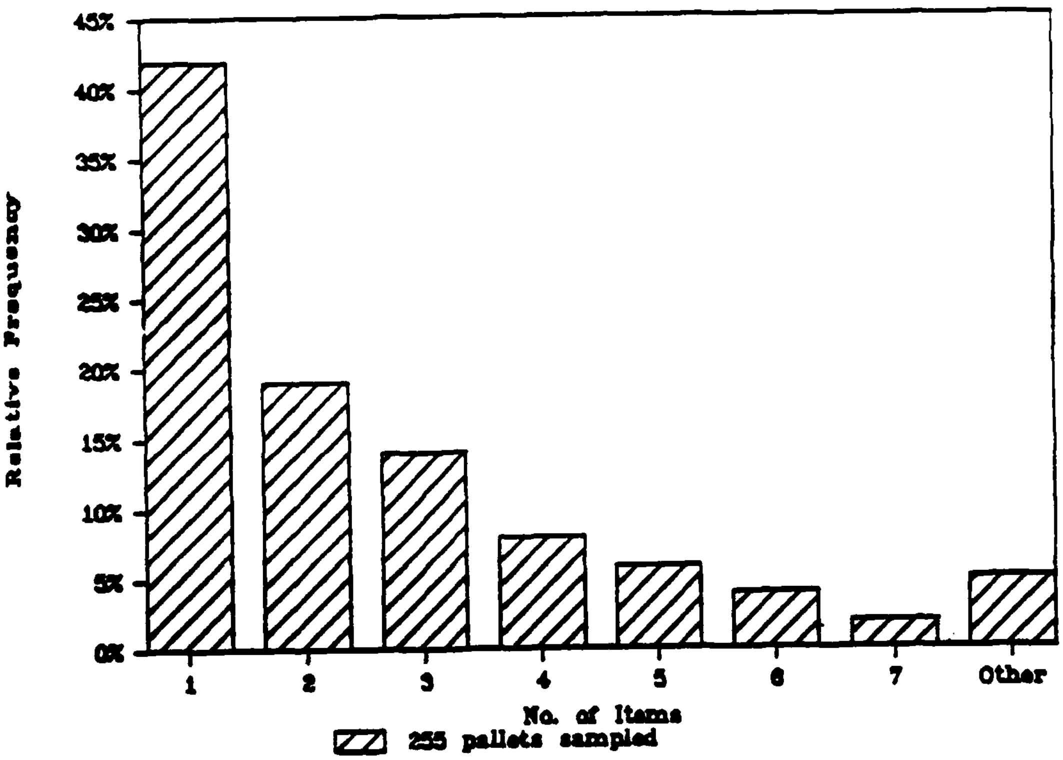


FIGURE 2A SAMPLE OF LINES PICKED PER PALLET

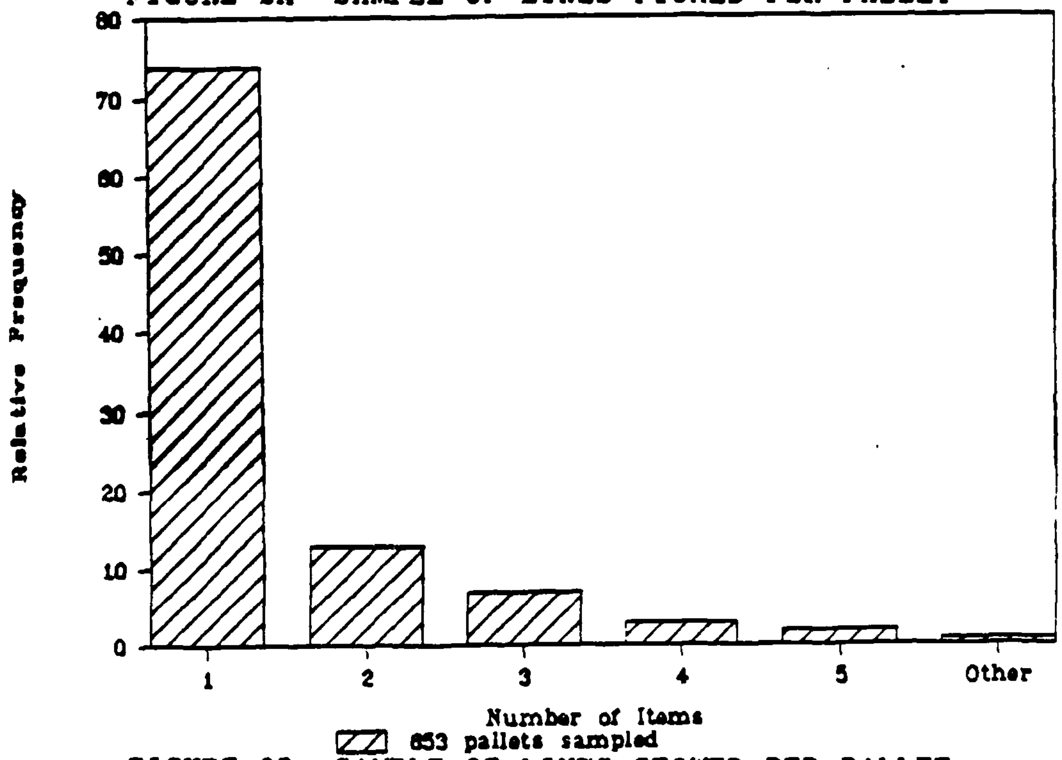


FIGURE 2B SAMPLE OF LINES STOWED PER PALLET

Time elements for the picking and stowing operations are grouped into segments corresponding to issue preparation, document processing, maneuvering, lift/lower, and other miscellaneous operations. The times have been computed and a 13.9% Personal, Fatigue, and Delays (PF&D) allowance has been provided. These segments were further consolidated into two components: fixed (or base) time and travel time. See Table 4. The fixed time component is determined by the human performance standard and is independent of system size. The travel time component is variable and is directly related to system layout, item density, and inventory size.

The base component generally accounts for 67% of the picking time. The remainder of the time is represented by the travel component for conventional forklift equipment. This time element has been removed for the study so that the operating specifications for the S/R machine could be included.

TABLE 4

BASIC COMPONENTS OF THE HUMAN PERFORMANCE TIME STANDARDS

Operation	Base (min.)	Travel (min.)	Total (min.)
Picking	7.70	3.77	11.47
Stowing	11.74	2.83	14.57

The number of transactions per day for each function has been estimated from historical data and listed in the following table. The tabulated values do not include the projected increase in workloads over the next five years.

TABLE 5

DAILY NUMBER OF TRANSACTIONS
(LINE ITEMS)

	Average
MRO 'red'	Not available for public information
MRO 'green'	
MRO 'white'	
Total Picks	
Stows	
Transshipments	

The warehouse policy is to "get the right item, in the right amount, to the right place, in the right condition, on time, all the time." Therefore, the following priorities have been established in Table 6, for the various systems. The S/R machine is not involved in transshipments.

TABLE 6

PRIORITIES OF TRANSACTIONS

Transaction	AGV	S/R
Transshipments	1	---
MRO "red"	2	1
MRO "green"	3	2
MRO "white"	4	3
Stows	5	4

Both the AGVS and S/R system are involved in picking and stowing operations. The AGVS is responsible for the movement of receipt items from the receiving area to the storage area, and for the removal of the pick items from the storage area to the shipping area. The S/R system is responsible for movement of pick and stow items between the Input and Output (I&O) stations and the storage system.

The Hardware

The Warehouse Modernization and Layout Planning Guide (42) was utilized as a self-help guide for the development of the proposed Computer Aided Pallet Storage (CAPS) system. Construction specifications and building dimensions outlined in this guide were altered to design a storage structure that met the specific needs of the CAPS system.

A free standing storage structure is to be constructed. This type of structure is supported by steel framing and insulated metal siding. Tubular internal columns are often used to support the inner weight of the roof. The roof is generally constructed of a single layered membrane covered with tar, felt, or a gravel buildup.

The conventional beam type pallet rack is to be used. The storage rack is assembled with structural uprights joined by pallet beams. The rack depth for a standard pallet rack is 40 inches which is the same depth as the pallets themselves. To avoid loads from falling between the beams "pallet support members" are installed between the beams as shown in Figure 3.

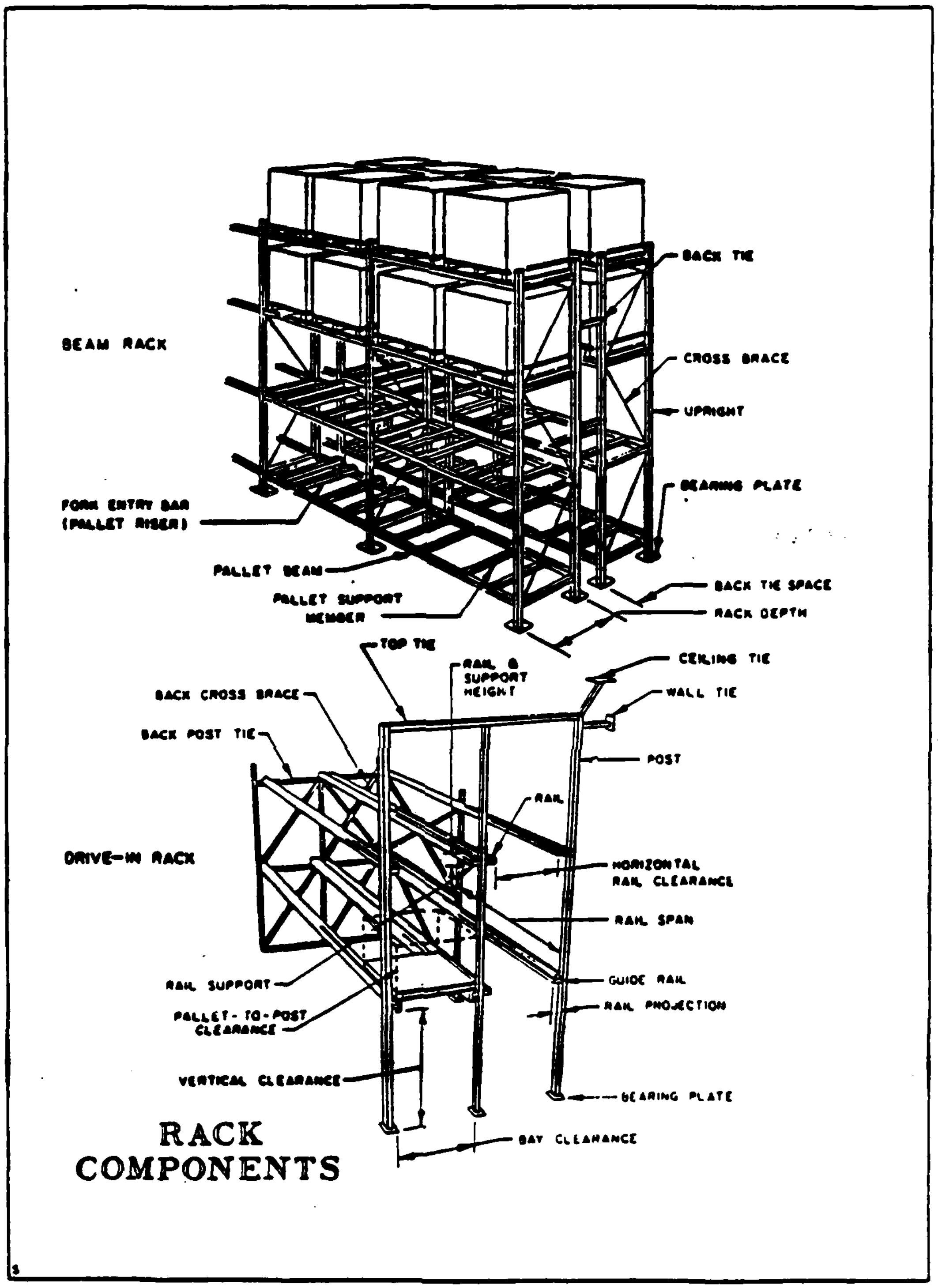


FIGURE 3 RACK COMPONENTS

The typical pallet rack elevation and storage level heights for standard 40" deep, 48" wide, and 36" high pallets and stored ten levels high are shown in Figure 4. The 40 feet stacking height (SH) is the maximum permitted by management at XYZ company. The 40 feet indicates allowances for the 12" from the floor to the top of the first level, the horizontal structural 4 inch beams across the face of each pallet rack, and the clearance required between the top of the pallet and the rack beam. Allowances are provided for approximately four inches of over-travel and at least eight inches of clearance above the pallet. The pallet rack has a uniform beam spacing of 4 feet which accommodates pallets that are 3 feet high or less.

A 100% sample of the pallets to be stored in the warehouse complex was collected to determine the distribution of pallet load heights. This information is shown in Table 7 (heights include the pallet skid). The data indicates that the pallet loads vary considerably in height and that only 71 percent of the pallets would fit in the rack illustrated in Figure 4. Also the mean height of all the pallets was 32 inches or 2.67 feet which is less than the standard 36 inch high pallet shown in Figure 4. By varying the beam spacing to fit the pallet heights, better cube utilization could be achieved.

TABLE 7

PALLET LOADS BY HEIGHT

Height (feet)	Number (pallets)	Accumulative Percent (%)
1.0	1606	6.0
1.5	4332	21.0
2.0	4633	38.0
2.5	4748	55.0
3.0	4405	71.0
3.5	3860	85.0
4.0	2238	93.0
4.5	1277	98.0
5.0	688	100.0
Total	27787	

The maximum pallet height of each level was established by ordering the pallets in increasing height and finding the height that correspond to the pallet at each of the 10 percentiles (10, 20,...,100). Since the racks are to have 10 levels, 10% of the products have to be at each level.

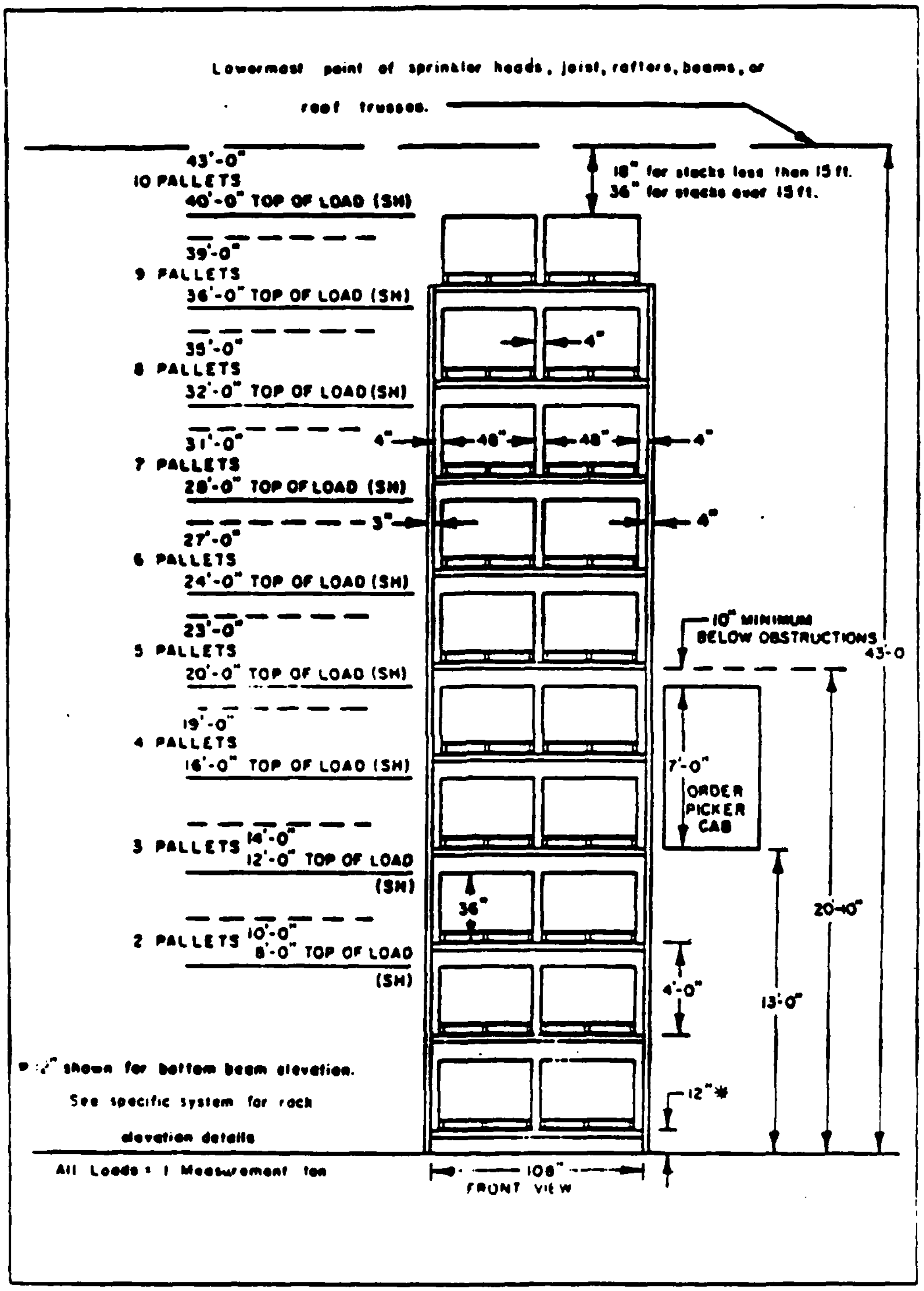


FIGURE 4 TYPICAL PALLET RACK ELEVATION

To fit the S/R machine the lowest support beam in the pallet rack must be elevated two feet above the floor level. The elevation of the second support beam is determined by adding the elevation of the first beam (2 feet), the maximum pallet height for the first level, the clearance allowance between the top of the pallet and the rack beam (8 inches or 0.66 feet), and the width of the supporting beam (4 inches or 0.33 eet). Ten percent of the pallet loads have a vertical dimension of 1.5 feet or less. Therefore the elevation of the second beam is

$$2.0 + 1.5 + 0.66 + 0.33 = 4.5 \text{ feet.}$$

Subsequent storage elevations are computed in a similar manner. The resulting beam spacings, vertical load openings, and stack heights (SH) are shown in Table 8.

TABLE 8

SPACING OF STORAGE RACKS

Level	Support Beam Elevation (feet)	Pallet Height (feet)	Stack Height (feet)
1	2.0	1.5	3.5
2	4.5	2.0	6.5
3	7.5	2.0	9.5
4	10.5	2.5	13.0
5	14.0	2.5	16.5
6	17.5	3.0	20.5
7	21.5	3.0	24.5
8	25.5	3.5	29.0
9	30.0	4.0	34.0
10	35.0	5.0	40.0

The rack with the shortest vertical dimension is placed at the bottom and each level is progressively larger until the tallest pallets are placed on the top level. Variable height spacing will generate better cube utilization of the rack structure, but some variations from the ideal may be necessary. For example, if all the proper size spaces for a particular size pallet are occupied, a pallet may need to be stored at a higher level than necessary or split into 2 pallets of smaller size.

An additional 3 feet of clearance is required between the top of the uppermost pallet and the lowermost point of sprinkler heads, hoist, rafters, beams, or roof trusses. This clearance helps prevent damage to the structure, sprinkler system, and electric lines. The inner height of the structure must be a minimum of 43 feet. A pictoral representation of the information presented in Table 8 can be found in Figure 5.

To achieve maximum operating effeciency for the S/R machine the pallet rack is designed to be 'square in time'. In other words, it takes the S/R machine an equal amount of time to reach the highest level as it does to reach the most distant column. Since the S/R machine can travel horizontally and vertically simultaneously, it can reach the most distant point (the top row at the most distant column) in the same amount of time it takes to reach either the top row or the most distant column. The rackface was designed for one type of S/R machine. Other S/R machines could be considered but the dimensions of the storage racks might vary.

The specifications for the S/R machine are:

- horizontal speed of 5 miles per hour (440 feet/min.)

- vertical speed of 1 mile per hour (60 feet/min.)

Therefore, the time to reach the highest level is:

40 ft. / 60 ft. / min. = 2/3 min. or 40 secs.

The horizontal distance that can be travelled in 2/3 min. is:

440 ft / min. * 2/3 min. = 293 ft.

From Figure 4, a double rack (holding two pallets) is 112 inches or 9.33 feet wide. The number of pallet locations per level is:

293 ft. / (9.33 ft./ 2 pallet locations) = 64 pallets

The number of pallets per rack face is:

64 pallets/level * 10 levels = 640 pallets

The number of pallets per aisle is 2 * 640 = 1280 pallets

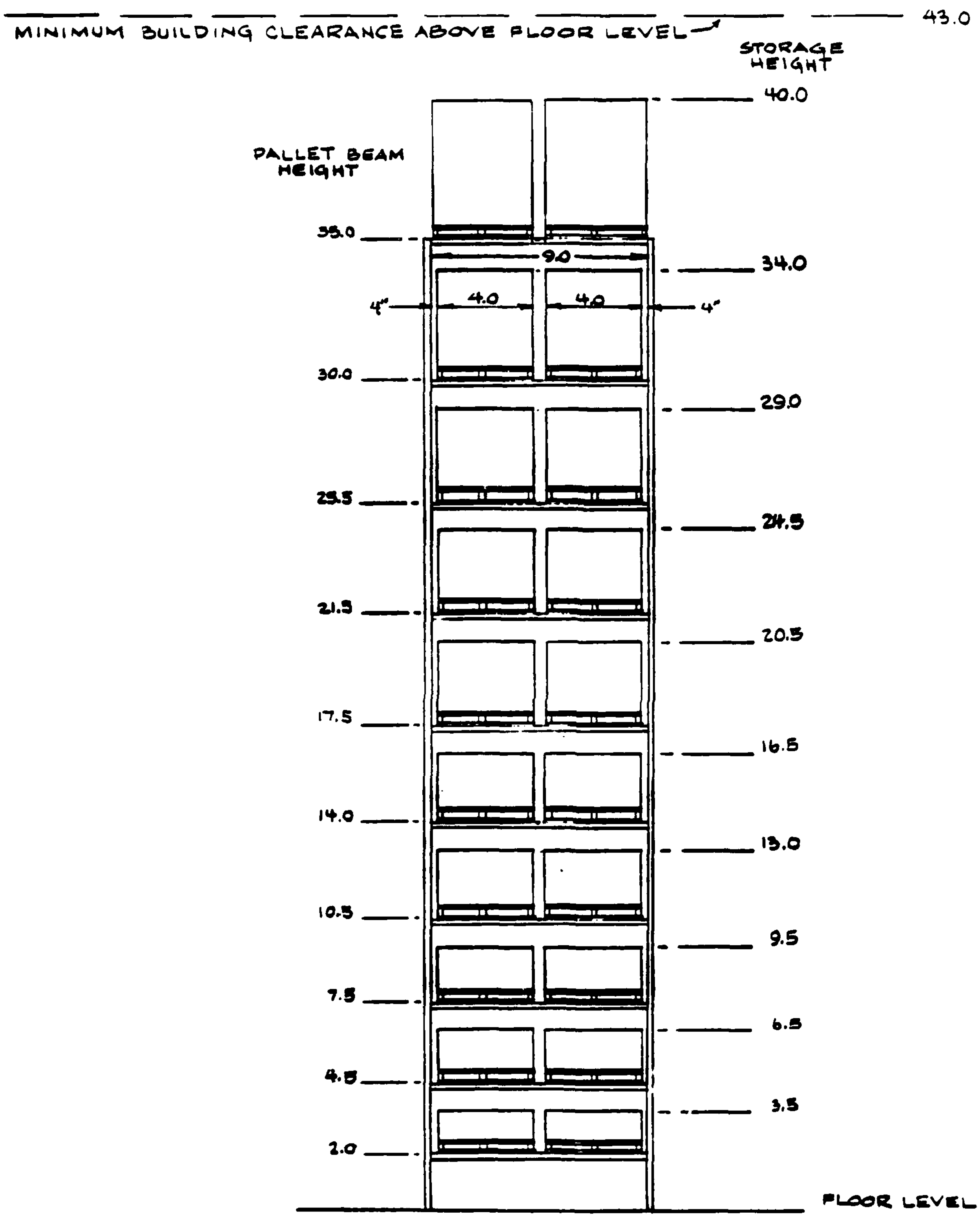


FIGURE 5 CAPS PALLET RACK ELEVATION

Computing the Number of Aisles

The five year workload projection suggests that 40000 pallets locations will be required. Therefore, the number of aisles required are:

40000 pallets / 1280 pallets / aisle = 31 aisles.

Computing Floor Area

The standard layout module for person-on-board S/R machines is shown in Figure 6. The aisle specifications assume that the pallets have zero inches of overhang into the aisle. To compensate for aisle overhang the aisle width has been increased to 60 inches. Also, for interaisle movement of the S/R machine, a 25 foot rear court bay is required. As shown in Figure 7, the front court bay must also be extended to 25 feet to accommodate 15 feet of input and output stations and 10 feet for the AGV pathways. Therefore, the total length of the storage structure is roughly (300+25+25) 350 feet.

One storage aisle, including rack depths, and flue space is 12.58 feet wide: therefore, the total width of the storage structure is (12.58*31) 390 feet wide. The free standing structure would occupy (350*390) 136500 square feet of storage space.

The Warehouse Modernization and Layout Planning Guide (42) recommends that support columns be placed between every other aisle (or every (2*12.58) = 25.2 feet) and on 35.9 foot centers. To maintain consistency within the proposed 350 foot long structure, 35 foot centers are recommended. As shown in Figure 8, the total number of internal support columns required is 135. The total number of external support columns required is 50. A summary of the storage specifications is found in Table 9.

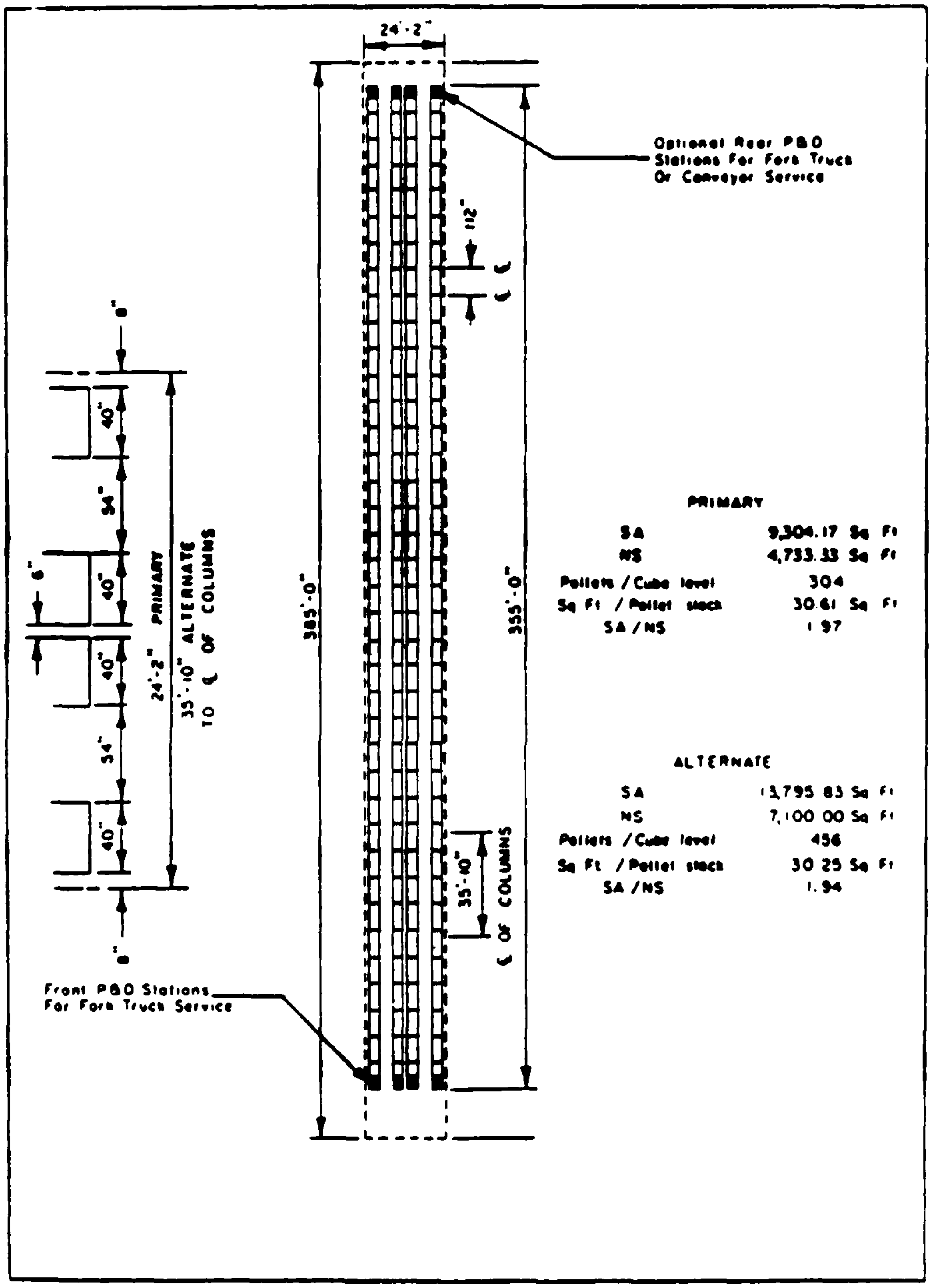


FIGURE 6 MODULAR LAYOUT FOR A PERSON-ON-BOARD S/R MACHINE

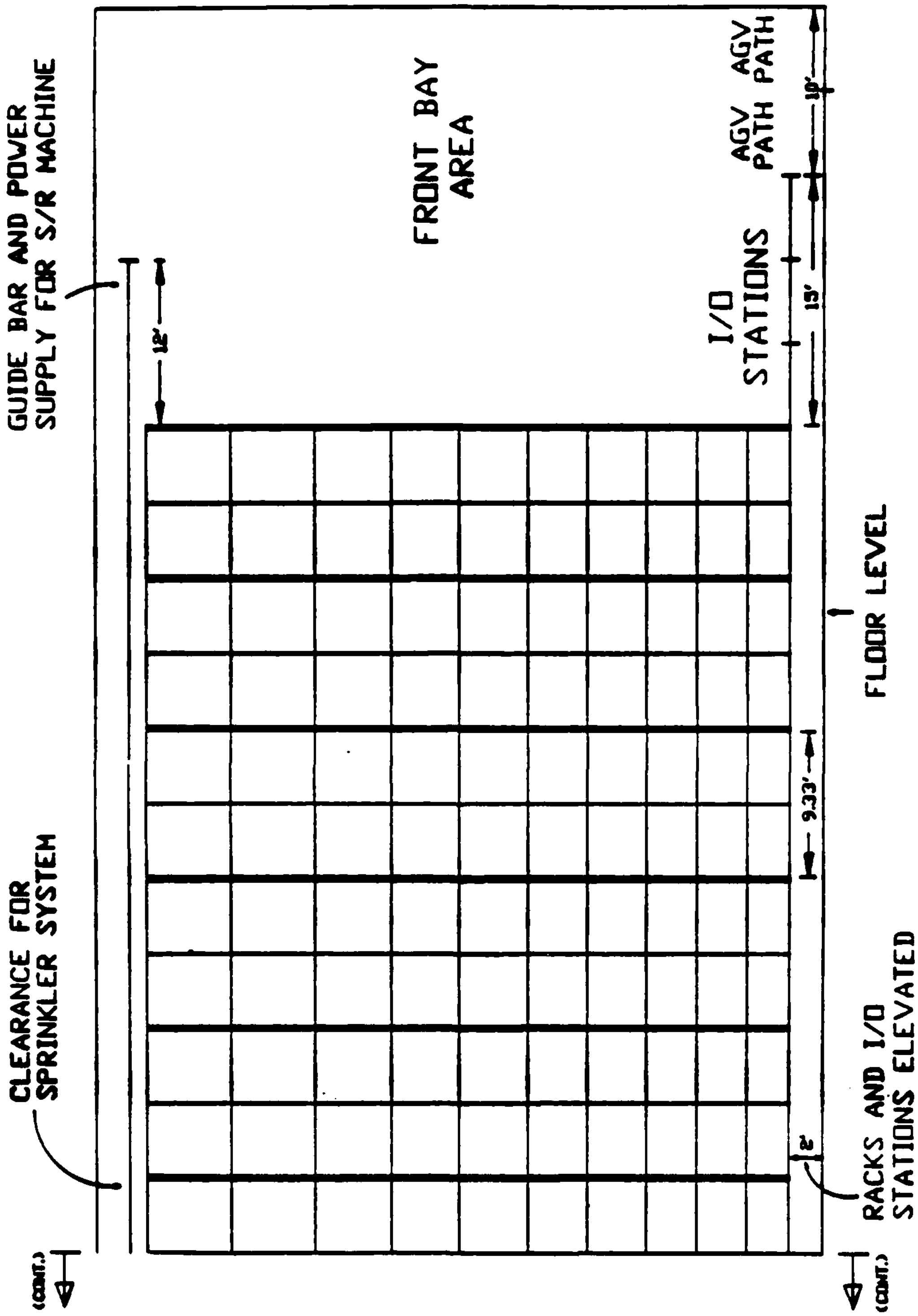


FIGURE 7 CAPS FRONT COURT BAY AREA

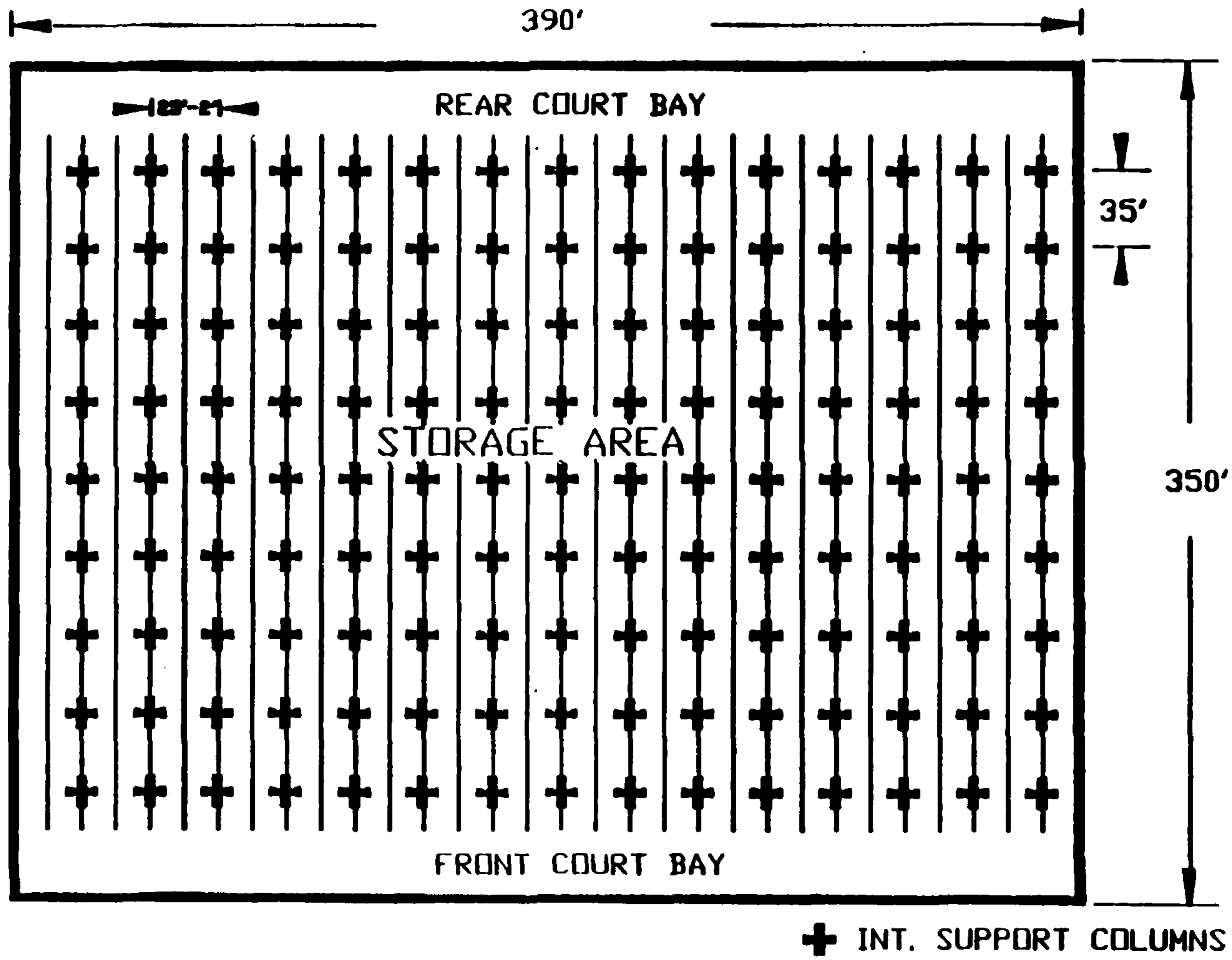


FIGURE 8 CAPS STORAGE AREA (Top View)

TABLE 9

STORAGE STRUCTURE SPECIFICATIONS

Width of a pallet location	4.67 feet
Number of pallet locations / level	64
Number of locations / rack	640
Number of locations / aisle	1280
Number of aisles	
Initially	24
Future	31
Length of pallet rack	300 feet
Length of Front Court Bay	25 feet
Length of Rear Court Bay	25 feet
Overall Length	350 feet
Width of two pallet rack	6.67 feet
Width between racks	0.92 feet
Width of aisle	5.00 feet
Width per storage aisle	12.59 feet
Overall Width	390 feet
Overall square footage	1365000 feet**2
Spacing between columns	
Lengthwise	35.0 feet
Widthwise	25.17 feet

S/R Machine

An Automated Storage and Retrieval System (AS/RS) is typically an unmanned operation. Such systems are more susceptible to logistic failures due to mechanical malfunctions and power outage. A person-on-board system is considered more fail-safe and can be expanded or altered rapidly by the addition of basic automation. For the in-aisle orderpicking system the person-on-board S/R machine has been recommended. The S/R operator goes to the storage location and places the picked item on the pallet. The pallet is then carried to the front of the aisle for dispatching.

The person-on-board S/R machine offers the benefits of a narrow aisle orderpicking vehicle and unit load S/R machine. The S/R machine is equipped with a tall rigid mast which is anchored to a upper guidance system. The mast is equipped with a shuttle table that is capable of handling the pallet loads. The pallet handling mechanisms are similar to those used on conventional forklift trucks.

The base of the vehicle consists of a battery powered wheeled platform which permits the person-on-board machine to drive between aisles in a manner similar to a conventional orderpicking vehicle. Outside the storage aisle, the S/R machine runs on batteries. When the S/R machine is operating in the storage aisle, the power is supplied by an overhead collector bar.

The use of upper and lower guide rails provides added stability which reduces the 'flag pole' effect common in most high lift fork trucks and eliminates the need for load derating. Therefore, the full lift capacity is available over the entire lift range. Specifications for the S/R machine are based on the information given in Table 10.

The S/R machine works within the storage system, and interfaces with Input (I) and an Output (O) stations located at one end of each aisle. The I/O stations act as an intermediate storage buffer and transfer devise between the S/R system and the Automatic Guided Vehicle System (AGVS).

TABLE 10

S/R SPECIFICATIONS

Horizontal acceleration	- 3 feet/second
Horizontal speed	- 440 feet/minute
Vertical acceleration	- 1 foot/second
Vertical speed	- 60 feet/minute
Load/Unload time	- .33 minutes
Interaisle travel time	- 5.0 minutes

The input station is in front of the output station so that a AGV can make a Dropoff (D) and a Pickup (P) in the same aisle. The I&O stations are elevated to the same height as the AGV and no special equipment is needed for raising or lowering the pallet load.

The I&O stations are active or powered roller conveyors. The input conveyor transfers the pallet load from the AGV to the S/R machine. The loads are moved forward to fill the last available position. No pressure or contact is permitted between the pallet loads for easy removal by the S/R operator. The pallets are obviously handled on a First Come First Serve (FCFS) basis. When the input station reaches capacity the conveyor is blocked and no more dropoffs are permitted.

The output conveyor transfers the pallet load from the S/R machine onto the AGV. The powered roller conveyor must therefore have the versatility to perform accumulation, switching, timing, and scheduling of materials. The pallets are again advanced on a FCFS basis. When the output station reaches capacity the conveyor is blocked and no more deliveries are permitted by the S/R machine. The specifications for the I/O stations were obtained from existing equipment measurements and are given in Table 11.

TABLE 11

I/O STATION SPECIFICATIONS

Length / pallet position	5 feet
Width of station	3.5 feet
Height of stations	2.0 feet
Number of Input Stations	
Storage Area	
Present	24
Future	31
Shipping Area	--
Number of Output Stations	
Receiving Area	
Stow Trans.	6
Transshipments	1
Storage Area	
Present	24
Future	31

To prevent jamming, tapered pins would be used to align the AGVs to the I&O stations. The AGVS is responsible for moving palletized loads from the receiving area to the storage area, and for the removing palletized loads from the storage area to the shipping area. For transshipments, the AGVS moves palletized loads directly from the receiving area to the shipping area.

The track layout for the AGVS is shown in Figure 9. The lengths of each segment is given below in Table 12. The track segment between Control Points (CP) 80 and 90 is used for a parking zone for any AGV that does not have a pickup or dropoff assignment.

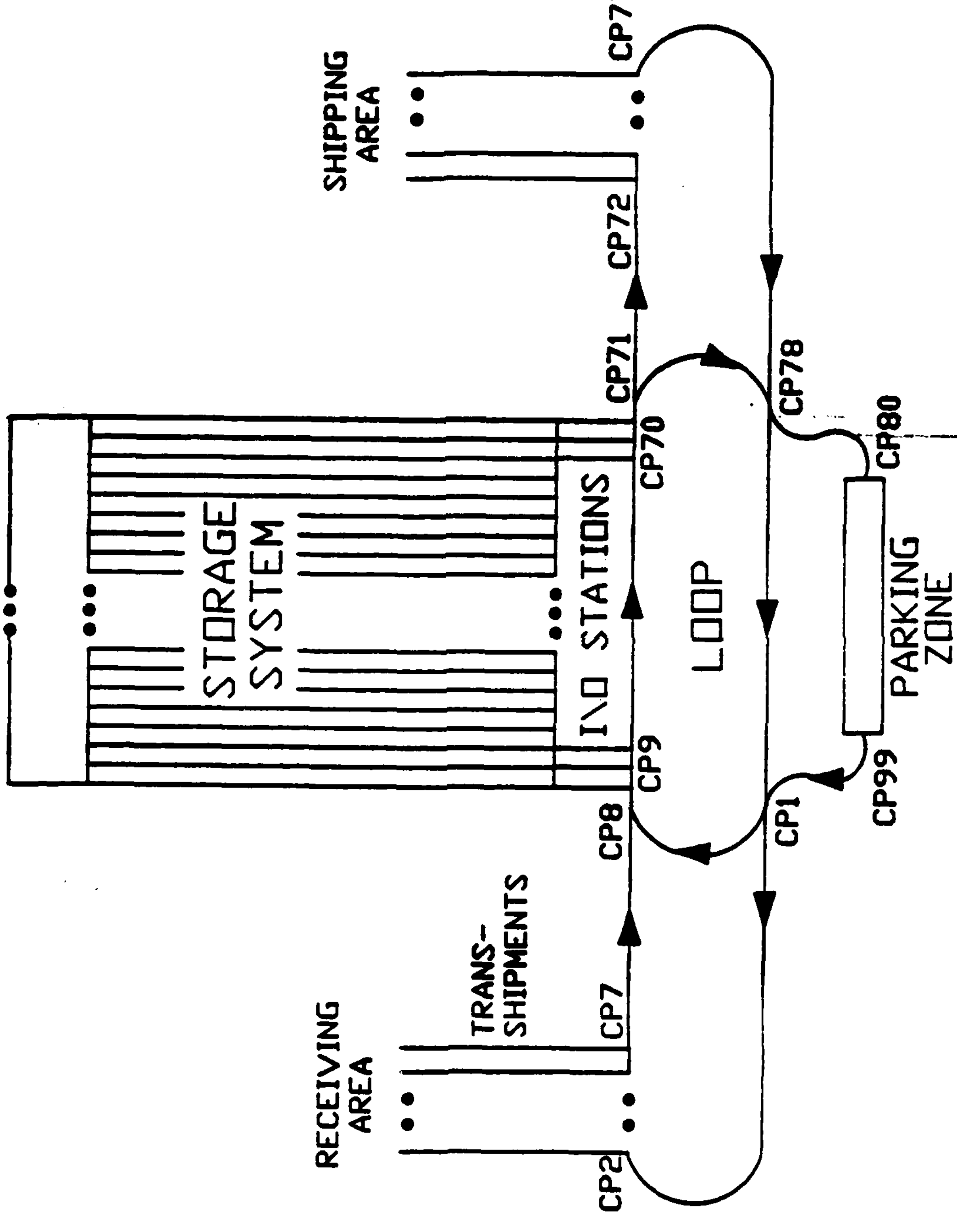


FIGURE 9 CAPS WAREHOUSE LAYOUT

TABLE 12

AGV TRACK LAYOUT

Track Segment End Points	Length (feet)
CP1 - CP2	960
CP7 - CP8	920
CP8 - CP9	15
CP9 - CP70	390
CP70 - CP71	15
CP71 - CP72	250
CP77 - CP78	250
CP78 - CP1	390
CP78 - CP99	407

Sensors on-board the AGVs are used to follow the pathways. Communications between the vehicle and the I&O stations are conducted through the guidance wire. Decisions for selecting a task and selecting and routing a AGV are made by the computerized controller system or by warehouse workers who use remote input terminals. Remote terminals are located in the receiving area to dispatch stow and transshipment transactions.

The AGVs are independently powered by batteries. The internal storage batteries must last up to 14 hours on a single charge. The AGV speed and time specifications are shown in Table 13.

TABLE 13

AGV SPECIFICATIONS

Loaded speed	80 feet/minute
Unloaded speed	100 feet/minute
Load time	0.33 minutes
Unload time	0.33 minutes

A major component of the S/R system is the document processing time. This function generally accounts for 20% - 32% of the base time. A computer assisted orderpicking system can reduce this time, eliminate paper work, correct or compensate for errors in inventory location and quantity, and provide a real time response to the order picker. This capability could increase the system throughput or enable fewer stackers and AGV's to meet the required service level.

Operating Policies

The sequencing of pick orders before sending them to the order pickers is an important element in the overall efficiency of the order picking operation. The pick order consists of the customer's name or code number, storage address, requested item, product description, and quantity. The above information is available from the Material Reciept Order (MRO). The pick orders are then sequenced by priority (as discussed previously), aisle, column, and row. The items are stored in a class based storage system. The classes are based on the pallet loads height. There are seven classes: 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, and 5.0 feet. Pallet loads greater than five feet can not be handled by the S/R machine and are therefore kept in another storage area. Items are stored randomly; each item has an equal chance of being stored in any of the storage locations within its class.

Since emphasis is placed on completing all MROs ".... on time, all of the time", a noninterleaving policy has been adopted. In this situation, the operator of the S/R machine performs all retrieval (pick) operations before performing storage (stow) operations. No storage operation and retrieval operation will be performed in the same cycle.

Since, there is one S/R machine per storage aisle, the S/R system is considered to be "aisle captive" except for mechanical failures. Thus, a zone picking method has been adopted for the orderpicking policy. In this case, the MROs of each aisle are assigned to the S/R machine operator of that aisle. If the S/R operator completes all orders in that aisle he/she then proceeds to stow items for that aisle. Only one S/R machine is permitted in a aisle at a time.

For manhandle packages the items are batched or lotted by random assignment. In this situation, the next item is scanned by order sequence to see if the item will fit on the picking lot being formed. The number of line items to be lotted per pallet has been sampled and is depicted in Figure 2A. If the next item has a different priority, the lot being formed is carried to the end of the aisle for dispatching. Only one item is lotted per unit load. Stows are also treated as unit loads since lotting would require additional sorting in the receiving area.

AGVs are dispatched on a First Come First Serve (FCFS) bases. If additional vehicles are needed in a particular area the computer will direct idle AGVs to that area. Otherwise, the AGV will remain at the parking zone. AGVs are directed by the controller to take the shortest path to the next destination. If more than one pallet is waiting when a AGV becomes available, the pallet with the highest MRO priority is selected. Ties in MRO priority are broken by selecting the pallet that has been waiting the longest.

Assumptions for the Simulation Model

The model assumes that all S/R machines and AGVs have the resources available (i.e. battery charge) to operate for a second shift. The model also assumes that similar vehicles have identical capabilities and travelling speeds.

CHAPTER 4

MODEL PERFORMANCE

Model Testing

As the simulation model was being developed, a detailed trace of the simulation was periodically printed to verify that the model was performing correctly. SLAM and its AGV extension provide trace facilities which automatically output the result of each model statement, as well as any variables requested by the user and the time of each event. Below is narrative version of two pick transactions and one stow transaction run through the system. The trace was developed to verify the performance of the model. The time of each event and a brief description of each are provided. Hand calculations have also been prepared for comparison.

SLAM and MH Extension Trace

Time of Day	Description of the Event
SLAM 00:00.0 a.m. Cal. 00:00.0 a.m.	A customer order is received, requesting 1 line item (referred to as item # 1). The item is located in aisle 13, column 26, level 2. A 'red' Material Release Order (MRO) is prepared and held until day shift (6:30 a.m.).
SLAM 00:02:0 a.m. Cal. 00:02:0 a.m.	A second customer order is received, requesting 1 line item (referred to as item # 2). The item is located in aisle 7, column 29, level 4. A 'red' MRO is prepared and held until day shift.
SLAM 06:28.0 a.m. Cal. 06:28.0 a.m.	The computer sorts the MROs by priority, aisle, column, level, ascending, and descending order. MRO # 2 is placed first, and MRO # 1 is placed second.
SLAM 06:30.0 a.m. Cal. 06:30.0 a.m.	The orders are released for picking at the beginning of day shift.

S/R machine unit 4 is available for operation in aisle 7. The S/R machine is initially located at the I/O station and travels to the storage location: column 29, level 4.

The S/R operating time for MRO # 2 is calculated:
The travel time of the S/R machine accounts for the acceleration, maximum speed, and deceleration of the S/R unit. The horizontal distance traveled =

29 columns * 4.67 ft/columns = 135.43 ft

The travel time during acceleration or deceleration =

440 ft/min / 7200 ft/min**2 = 0.06 min

The distance traveled during acceleration or deceleration =

7200 ft/min**2 * (0.06 min) ** 2 / 2 = 12.96 ft

The travel time at maximum velocity =

(135.43 ft - 2 * 12.96 ft) / 440 ft/min = 0.25 min

The total horizontal traveling time to storage column 29 =

0.06 min + 0.25 min + 0.06 min = 0.37 min

The vertical distance traveled =

3.0 ft + 3.5 ft + 3.5 ft = 10 ft

The travel time during acceleration or deceleration =

60 ft/min / 3600 ft/min**2 = 0.017 min

The distance traveled during acceleration or deceleration =

3600 ft/min**2 * (0.017 min) ** 2 / 2 = 0.52 ft

The travel time at maximum velocity =

(10.0 ft - 2 * 0.52 ft) / 60 ft/min = 0.15 min

The total vertical traveling time to storage level 4 =

0.017 min + 0.15 min + 0.017 min = 0.184 min

The travel time to the storage location: column 29, level 4 =

Max (0.37 sec, 0.184 sec) = 0.37 ft

The human time element for order picking = 6.16 min

S/R machine unit 4 attempts to lot additional orders. No other orders with a 'red' priority are located in aisle 7. The S/R unit returns to output station 7. The total time of order picking cycle =

0.37 min + 6.16 min. + 0.37 min = 6.90 min

There is no S/R machine in aisle 13, therefore the closest aisle is checked for an available unit. S/R unit 7 is available in aisle 12, and an operator moves the unit to aisle 13.

<u>The S/R operating time for MRO # 1 is calculated:</u>
The travel time between aisles =

12.59 ft / 88 ft/min = 0.143 min

The base time for movement between aisles including maneuver between aisles, the lining up of guiderails, and the travel time to and from I/O stations

= 5.0 min

The total interaisle travel time =

0.143 min + 5.0 min = 5.143 min

S/R unit 7 begins traveling to the storage location of item # 1. The intra-aisle travel time to and from the I/O station is computed in the same manner as item # 2.
The total travel time =

Max (0.34 min, 0.067 min) * 2 = 0.68 min

The human time element for order picking = 6.16 min

S/R machine unit 7 attempts to lot additional orders. No other orders with a 'red' priority are located in aisle 13. The S/R unit returns to output station 13.

The total time of order picking cycle =

5.143 min + + 0.68 min + 6.16 min = 11.983 min

SLAM	**06:36.9 a.m.**	**S/R unit 4 begins unloading the pallet** containing item # 2, onto output station 7. The unloading time = 0.33 min.
Cal.	06:36.9 a.m.	
SLAM	06:37.2 a.m.	The unloading of S/R unit 4 at output station 7 is complete. The unit becomes idle.
Cal.	06:37.2 a.m.	

Output station 7 advances the pallet **containing item # 2 toward the AGV pickup station. The time in transit =** 0.33 min

SLAM	**06:37.6 a.m.**	**The pallet is available for pickup by an AGV. An electronic signal is sent to the controller to dispatch a unit. AGV** unit 1 is assigned to the pallet containing item # 2 at output station 7.
Cal.	**06:37.5 a.m.**	

<u>The AGV operating time for MRO # 2 is calculated:</u>
The travel time for the AGV is computed at maximum speed. AGV unit 1 is initially located at control point 99.
The unit must travel track segments:

99, 80, 8, 9 - 21

		The total distance traveled =
		6.3 ft + 15 ft + 15 ft + 13 * 6.3 ft = 118.2 ft
		The travel time to output station 7 =
		118.2 ft / 120 ft/min = 0.985 min
SLAM Cal.	06:38.7 a.m. 06:38.5 a.m.	AGV unit 1 arrives at output station 7 and begins loading the pallet containing item # 2. The time to load a pallet = 0.5 min
SLAM Cal.	06:39.2 a.m. 06:39.0 a.m.	AGV unit 1 is loaded and begins traveling to the shipping station. The unit must travel track segments:
		22 - 69, 70, 71, 72 - 73
		The total distance traveled =
		48 * 6.3 ft + 15 ft + 250 ft + 2 * 6.3 ft = 580 ft
		The travel time to shipping station =
		580 ft / 80 ft/min = 7.25 min
SLAM Cal.	06:42.0 a.m. 06:42.0 a.m.	S/R unit 7 begins unloading the pallet containing item # 1 onto output station 13. The unloading time = 0.33 min.
SLAM Cal.	06:42.3 a.m. 06:42.3 a.m.	The unloading of S/R unit 7 is complete. The unit becomes idle.
		Output station 13 advances the pallet containing item # 1 toward the AGV pickup station. The time in transit = 0.33 min
SLAM Cal.	06:42.6 a.m. 06:42.6 a.m.	The pallet is available for pickup by an AGV. An electronic signal sent to the controller to dispatch a unit. AGV unit 2 is assigned to the pallet containing item # 1 at output station 13.
		<u>The AGV operating time for MRO # 1 is calculated.</u>

AGV unit 2 is initially located at control point 98. The unit must travel track segments:

98 - 99, 80, 8, 9 - 33

The total distance traveled =

2 * 6.3 ft + 15 ft + 15 ft + 25 * 6.3 ft = 200.1 ft

The travel time to output station 13 =

200.1 ft / 120 ft/min = 1.67 min

SLAM 06:44.6 a.m.
Cal. 06:44.3 a.m.

AGV unit 2 arrives at output station 13 and begins loading the pallet containing item # 1. The time to load the pallet = **0.5 min**

SLAM 06:45.1 a.m.
Cal. 06:44.8 a.m.

AGV unit 2 is loaded and begins traveling to the shipping station. The unit must travel track segments:

34 - 69, 70, 71, 72-73

The total distance traveled =

36 * 6.3 ft + 15 ft + 250 ft + 2 * 6.3 ft = 504.4 ft

The travel time to the shipping station =

504.4 ft / 80 ft/min = 6.30 min

SLAM 06:46.9 a.m.
Cal. 06:46.3 a.m.

AGV unit 1 arrives at the shipping station and begins unloading the pallet containing item # 2. The time to unload **the pallet =**
0.5 min

SLAM 06:47.4 a.m.
Cal. 06:46.8 a.m.

The unloading of AGV unit 1 is complete. The unit travels 'idle' with no other assignments to perform, to the parking zone.

Statistics on item # 2 are collected.
SLAM time in the system =

06:47.4 a.m. - 06:30.0 a.m. = 17.4 min

Calculated time in the system =

06:46.8 a.m. - 06:30.0 a.m. = 16.8 min

Customer order # 2 is complete.

SLAM	06:51.6 a.m.	**AGV unit 2 arrives at the shipping station and begins unloading the pallet containing item # 1. The time to unload the pallet = 0.5 min**
Cal.	06:51.1 a.m.	
SLAM	06:52.1 a.m.	**The unloading of AGV unit 2 is complete. The unit travels 'idle' with no other assignments to perform, to the parking zone.**
Cal.	06:51.6 a.m.	

__Statistics on item # 1 are collected.__
SLAM time in system =

06:52.1 a.m. - 06:30.0 a.m. = 22.1 min

Calculated time in system =

06:51.6 a.m. - 06:30.0 a.m. = 21.6 min

Customer order # 1 is complete.

SLAM	11:00.0 a.m.	A line item has arrived in the receiving area. The item (referred to as 'stow' item) is to be stored in aisle 9, column 24, **level 2. A receipt is prepared and the stow item is placed on a pallet made available for pick up by an AGV. An electronic signal is sent to the controller to dispatch a unit. AGV unit 3 is assigned to the pallet containing the stow item.**
Cal.	11:00.0 a.m.	

__The AGV operating time for the stow item is calculated.__
AGV unit 3 is initially located at control point 97. The unit muust travel track segments:

97 - 99, 1

The total distance traveled =

3 * 6.3 ft + 960 ft = 978.9 ft

The travel time to the receiving station

= 978.9 / 120 ft/min = 8.16 min

SLAM Cal.	11:08.1 a.m. 11:08.1 a.m.	AGV unit 3 arrives at the receiving station and begins loading the pallet containing stow item. The time to load the pallet = 0.5 min
SLAM Cal.	11:08.6 a.m. 11:08.7 a.m.	AGV unit 3 is loaded and begins traveling to input station 9. The unit must travel track segments: 2 - 6, 7, 8, 9 - 25 The total distance traveled = 5 * 6.3 ft + 928.5 ft + 15 ft + 17 * 6.3 ft = 1082.1 The travel time to input station 9 = 1082.1 / 80 ft/min = 13.53 min
SLAM Cal.	11:22.3 a.m. 11:22.2 a.m.	AGV unit 3 arrives at output station 9 and begins unloading the pallet containing stow item. The time to unload the pallet = 0.5 min
SLAM Cal.	11:22.8 a.m. 11:22.7 a.m.	The unloading of AGV unit 3 is complete. The unit travels 'idle' with no other assignments to perform, to the parking zone. Input station 9 advances the pallet containing stow item toward the S/R input station. The time in transit = 0.3 min
SLAM Cal.	11:23.1 a.m. 11:23.0 a.m.	The pallet containing the stow item becomes available for pickup. S/R unit 5 is in aisle number 9 and begins loading the pallet. The loading time = 0.3 min
SLAM Cal.	11:23.4 a.m. 11:23.3 a.m.	S/R unit 5 is loaded and begins traveling to storage column 24, level 2. <u>The S/R operating time for the stow item is calculated:</u>

The intra-aisle travel time =

Max (0.32 min, 0.13 min) * 2 = 0.64 min

The human time element for stowing =

9.78 min

The total time of the stowing cycle =

0.648 min + 9.78 min = 10.42 min

SLAM	11:33.9 a.m.	S/R unit 5 stops at I/O station 9 and
Cal.	11:33.7 a.m.	becomes idle.

Statistics are collected on stow item.

SLAM time in the system =

11.33.9 a.m. - 11:00.0 a.m. = 33.9 min

Calculated time in the system =

11:33.7 a.m. - 11:00.0 a.m. = 33.7 min

Stow item is complete.

Table 14 is a comparison of the SLAM time values and the hand calculated time values. The agreement of the SLAM II time values and the calculated time values for the S/R system and the I/O station appears to be within reason. The difference for MRO # 1 in the I/O system is attributed to round off error.

A comparison of the SLAM II time values and the calculated time values for the AGVS reveals a difference that was consistently higher for SLAM. A technical representative of Pritsker and Associates attributed the differences to the discrete time increments of continuous modeling. In this model the minimum (DTMIN = 0.0125 min) and maximum (DTMAX = 1.0 min) time increments were established in the VCONTROL statement.

SLAM II treats each control point (or node) of the AGV network as a special event. Within a minimum of one time increment (DTMIN = 0.0125) after passing a control point, SLAM II makes contention and routing decisions. SLAM reinitializes the starting point of the AGV at the control point but does not reduce the clock value by the fraction of

TABLE 14

COMPARISON OF TIME VALUES
(Minutes in the System)

System	SLAM II	Calculated	Difference
S/R			
MRO # 1	12.3	12.3	0.0
" " 2	7.2	7.2	0.0
Stow	10.8	10.7	0.1
I/O			
MRO # 1	0.3	0.3	0.0
" " 2	0.4	0.3	0.1
Stow	0.3	0.3	0.0
AGVS			
MRO # 1	9.5	9.0	0.5
" " 2	9.8	9.3	0.5
Stow	22.8	22.7	0.1
Total			
MRO # 1	22.1	21.6	0.5
" " 2	17.4	16.8	0.6
Stow	33.9	33.7	0.2

DTMIN by which the the AGV passed the node. This difference (averaging DTMIN / 2 or 0.00625 min) is insignificant, except when the AGV passes through several nodes between the start and destination nodes. In this model:

1. AGV unit 2 passed through 68 nodes in traveling to output station 7 and delivering MRO # 1 to the shipping station. On average this would result in a error of (68 * 0.00625 min) = 0.425 min.

2. For MRO # 2 AGV unit 1 passed through 67 nodes, roughly accounting for (67 * 0.00625 min) = 0.419 min of the difference.

3. AGV unit 3 passed through 25 nodes in transporting the stow item to input station 9. This accounting for a difference of (25 * 0.00625 min) = 0.156 min. in the SLAM II time values and the calculated time values. The remaining variation is attributed to round off error.

Simulation Runs

Following the development of the simulation model, a series of 6 test runs was performed to determine performance and assess the need for changes. A description of each of these 6 cases follows. Summary reports and graphs of the equipment utilization are included.

Case 1

For the first case, the model was tested as described in Chapter 3. A list of all the input variables and the operating policies for the AGVS and S/R system are provided in Appendix A.

The results of the SLAM Summary Report, abbreviated in Table 15, show that only thirty three percent of all the customer orders were processed and delivered to shipping for packing during the 8 hour shift. Zero percent of the stow items were stored.

The utilization of equipment was also poor, as shown in Figures 10A and 10B. The S/R machines were blocked fifty nine percent of the time whereas the AGVs were blocked sixty percent of the time.

A review of the SLAM Summary Report shows that the last transaction was delivered to shipping at 160.1 minutes (or 09:10.1 a.m.). A SLAM trace of the model showed that at 09:05.6a.m., AGV unit 14 attempted to unload a pallet at input station 9. Under the initial conditions, when the input station reached capacity, the conveyor was blocked and the AGV was not permitted to unload. Meanwhile, the S/R machines continued to retrieve and deliver customer orders to the output stations. When the output stations reach capacity, the S/R machines were blocked. In essence both the AGV and S/R systems experience blockage and became totally "locked up".

TABLE 15

SLAM Summary Report: Case 1

	Mean Value	Standard Deviation	Min. Value	Maxi. Value	Percent Complete
Red Orders	54.7	22.8	18.9	124.3	100
Green Orders	118.4	29.5	62.7	160.1	55
White Orders		No Values Recorded			
All Orders	82.0	40.9	18.9	160.1	33
Stows		No Values Recorded			

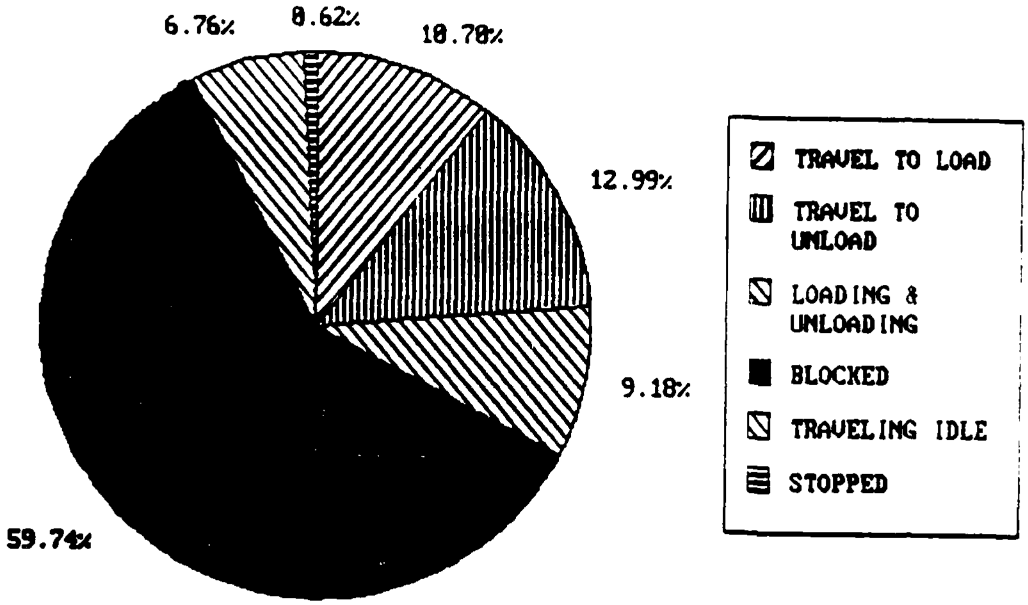


FIGURE 10A AGV UTILIZATION CHART: CASE :

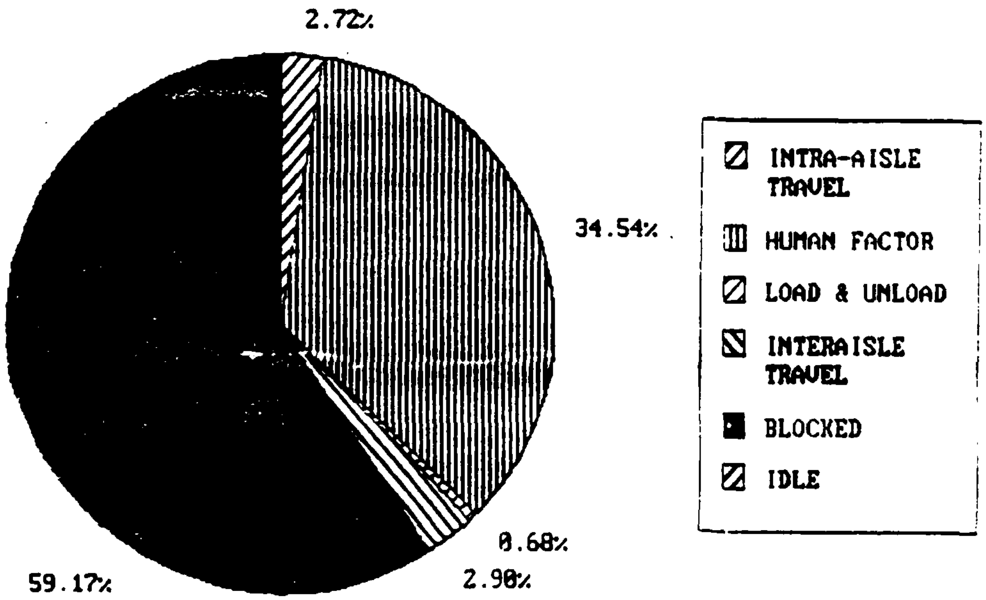


FIGURE 10B S/R UTILIZATION CHART: CASE .

Case 2

In the second case, the operating policy for unloading the AGVs was relaxed. If the input stations reach capacity the vehicle was directed around the 'loop' in the storage area. Refer to Figure 9.

The material flow was again sluggish. The throughput, for the pick transactions improved by twenty two percent, to a total of fifty five percent of the picks completed. Only four percent of the stow transactions were completed.

The AGVs filled the input stations early in the eight hour shift. The AGVs then traveled loaded with stow pallets, two hundred and sixty one times around the loop. The travel time around the loop accounted for thirty three the percent of AGVs total time (Refer to Figure 11A). In the mean time the S/R machines continued to pick orders until the output stations reached capacity. The S/R machines remained blocked for thirty nine percent of the total time, as shown in Figure 11B. The system responded poorly because the AGVs were unable to unload stow pallets.

The Case 2 Summary Report follows.

TABLE 16
SLAM Summary Report: Case 2

	Mean Value	Standard Deviation	Min. Value	Maxi. Value	Percent Complete
Red orders	54.7	22.8	18.9	124.3	100
Green orders	162.0	67.2	62.7	426.3	97
White orders	302.6	76.7	170.4	444.5	20
All orders	154.5	106.8	18.9	444.5	55
Stows	434.1	34.4	388.7	479.2	4

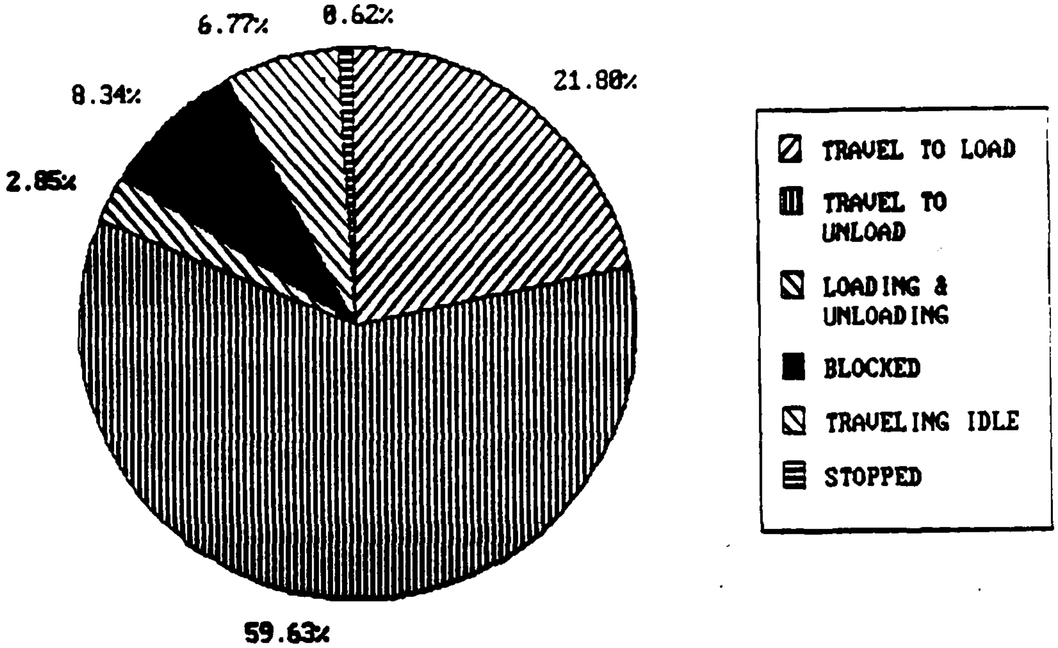


FIGURE 11A AGV UTILIZATION CHART: CASE 2

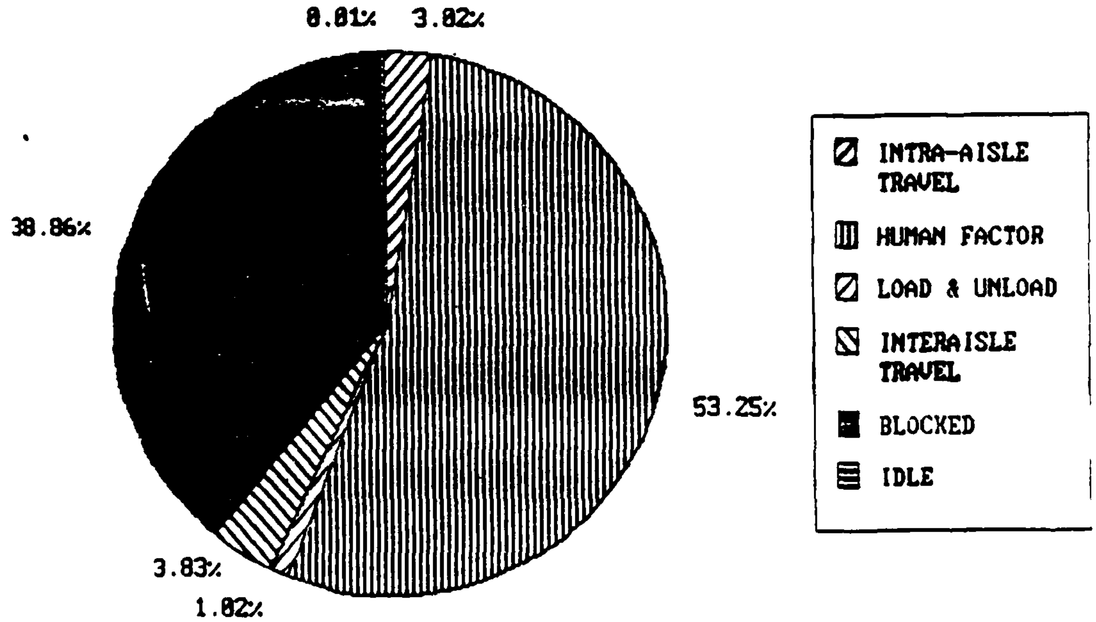


FIGURE 11B S/R UTILIZATION CHART: CASE 2

Case 3

In this case, the stow pallets were delayed in the receiving area until 11:00.0 a.m. As a result, the material flowed more smoothly through the system. As listed in Table 17, ninety four percent of all the pick transactions were completed and forty seven percent of the stow transactions were completed.

The AGVs traveled loaded only twelve times around the "loop" accounting for less than two percent of their total time. As shown in Figure 12B, the S/R machines were blocked less than three percent of the time.

A breakdown of the utilization of the S/R machines shows that:

1) five percent of the time, the units were in travel storing or retrieving items.

2) six percent of the time, the units were traveling between aisles.

3) one percent of the time the units were either loading or unloading pallets.

4) seventy one percent of the total time, the operators of the units were physically picking/storing items, or completing the proper documentation. The S/R machines remained stationary during this period of time.

TABLE 17
SLAM Summary Report: Case 3

	Mean Value	Standard Deviation	Min. Value	Maxi. Value	Percent Complete
Red orders	53.4	20.4	18.9	106.6	100
Green orders	128.0	35.2	62.7	238.9	100
White orders	271.3	87.3	139.6	475.8	89
All orders	188.5	112.8	18.9	475.8	94
Stows	403.5	45.2	320.9	478.8	47

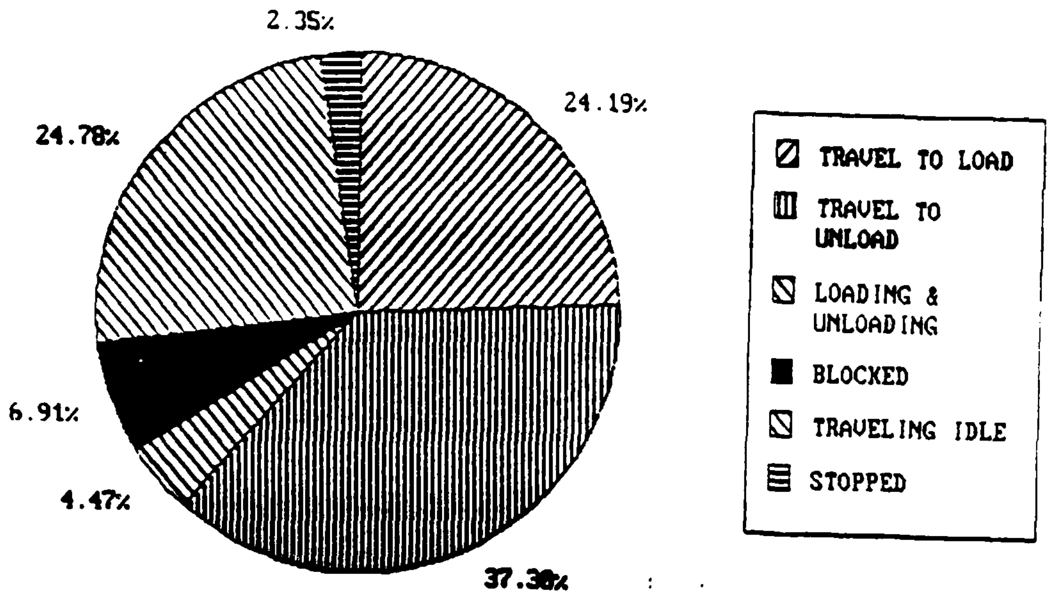


FIGURE 12A AGV UTILIZATION CHART: CASE 3

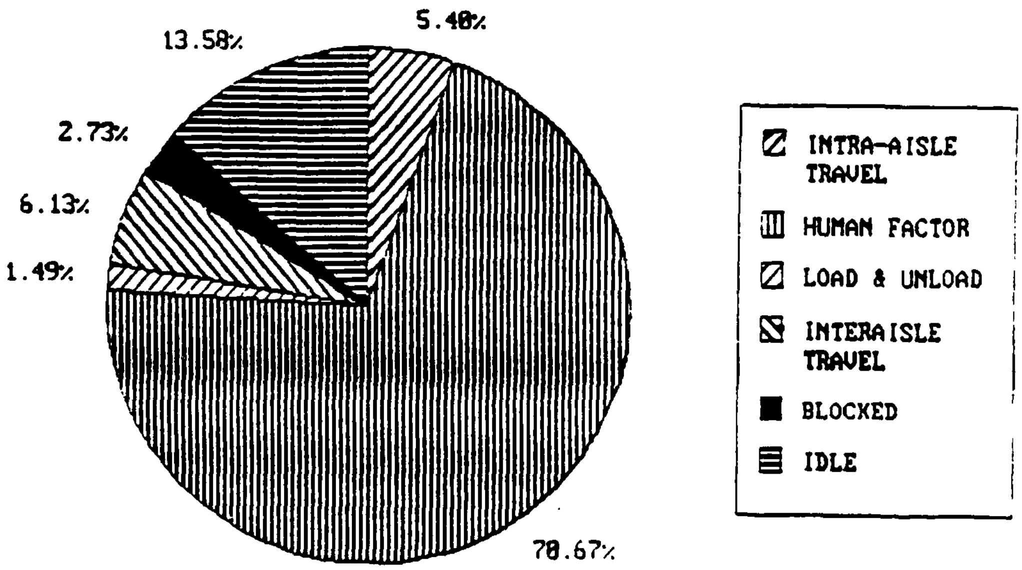


FIGURE 12B S/R UTILIZATION CHART: CASE 3

Case 4

In this case the AGV and S/R systems were tested for sensitivity when the human time standards were reduced by twenty percent. The resulting values for the human time elements were as follows:

storing [XX (42)] = 9.78 min/line item
retrieving [XX (43)] = 6.16 min/line item

The material continued to flow smoothly. As shown in Figure 13A, the AGVs remained blocked about seven percent of the total time. Ironically, the time the S/R machines were blocked dropped to one percent of the total time as Figure 13B illustrates. The reduction in the human time was offset by a thirteen percent increase in the S/R idle time. The twenty seven percent total idle time could be reduced, by reducing the number of S/R machines. Table 18 contains the **Case 4 Summary Report.**

TABLE 18
SLAM Summary Report: Case 4

	Mean Value	**Standard** Deviation	**Min.** Value	**Maxi.** Value	**Percent** Complete
Red orders	49.0	18.6	17.3	94.2	100
Green orders	112.3	30.2	57.7	206.0	100
White orders	233.5	68.2	122.2	468.1	98
All orders	167.2	93.5	17.3	468.1	99
Stows	**397.4**	**50.3**	**306.0**	**480.0**	**54**

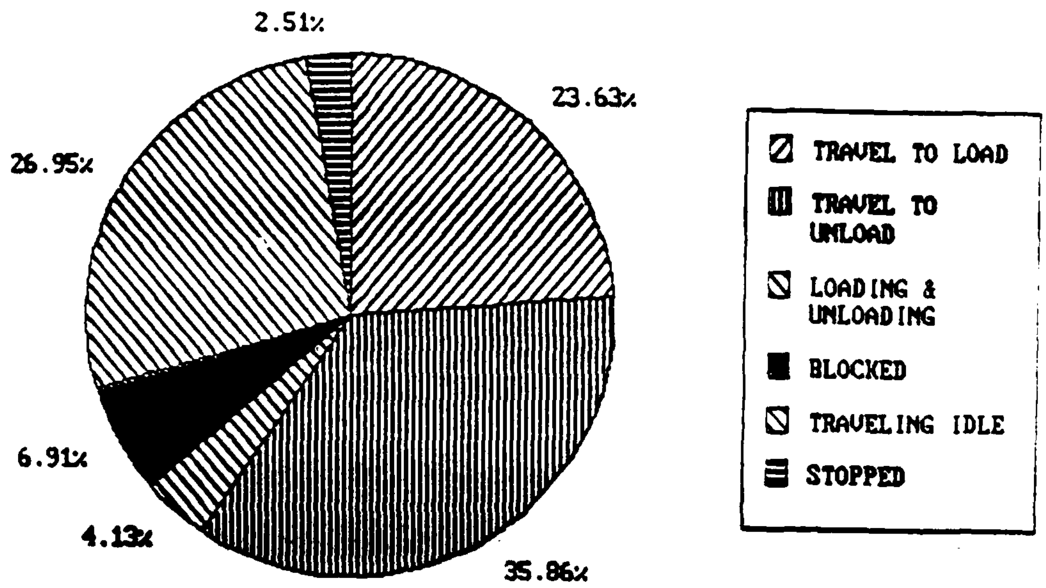


FIGURE 13A AGV UTILIZATION CHART: CASE 4

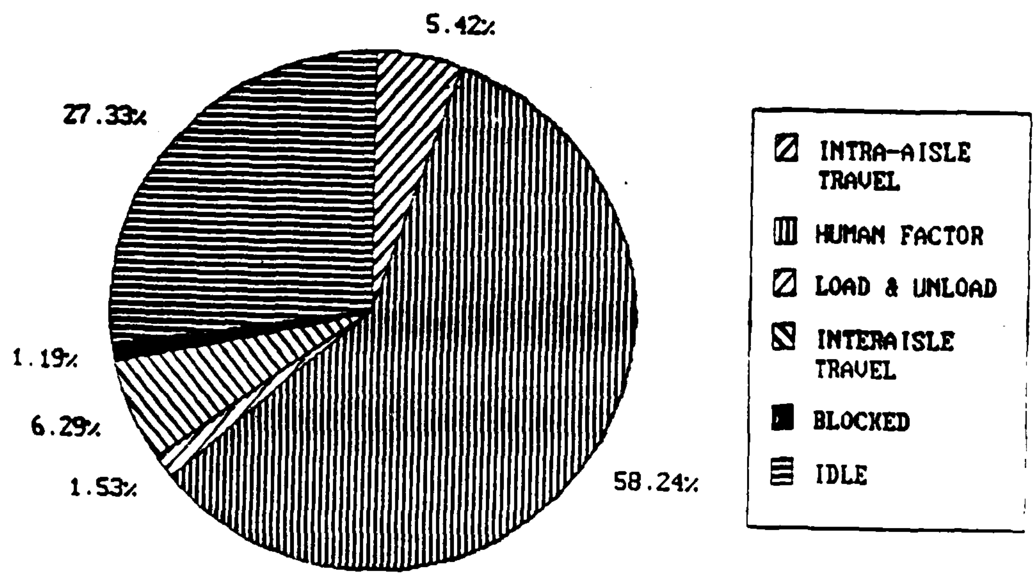


FIGURE 13B S/R UTILIZATION CHART: CASE 4

Case 5

In this case, the effect of increasing the number of AGVs by four, was determined. A statistical test was conducted to compare the results of the previous case (case 4) with the present one. The hypotheses state:

> **HØ: There is no significant difference in the mean transaction times of cases 4 and 5.**
>
> **H1: There is a significant difference in the mean transaction times of the two cases.**

The comparison was based on a ninety five percent confidence interval.

The results of the test summarized in Table 19, indicate that the HØ hypothesis should be accepted, that is, **there was no significant difference when the number of AGVs was increased by four.**

TABLE 19

Test Comparison of the Transaction Times

Transaction <u>Type</u>	Table <u>Value</u>	Calculated <u>Value</u>	Hypothesis Ø <u>Accept / Reject</u>
Red order	1.67	0.53	Accept
Green order	1.67	0.73	Accept
White order	1.66	0.35	Accept
All order	1.65	0.29	Accept
Stow	1.66	0.51	Accept

A review of the AGV utilization chart (Figure 14A), shows that the increase in the number of AGVs was offset by a fifteen percent increase in the travel "idle" time. The S/R utilization chart (Figure 14B) shows little change in how they were utilized.

TABLE 20

SLAM Summary Report: Case 5

	Mean Value	Standard Deviation	Min. Value	Maxi. Value	Percent Complete
Red orders	47.2	17.4	16.9	91.4	100
Green " "	108.8	29.1	55.2	200.3	100
White " "	230.8	71.2	119.6	475.0	99
All " "	165.0	94.5	16.9	475.0	99
Stows	401.2	49.9	307.5	478.7	67

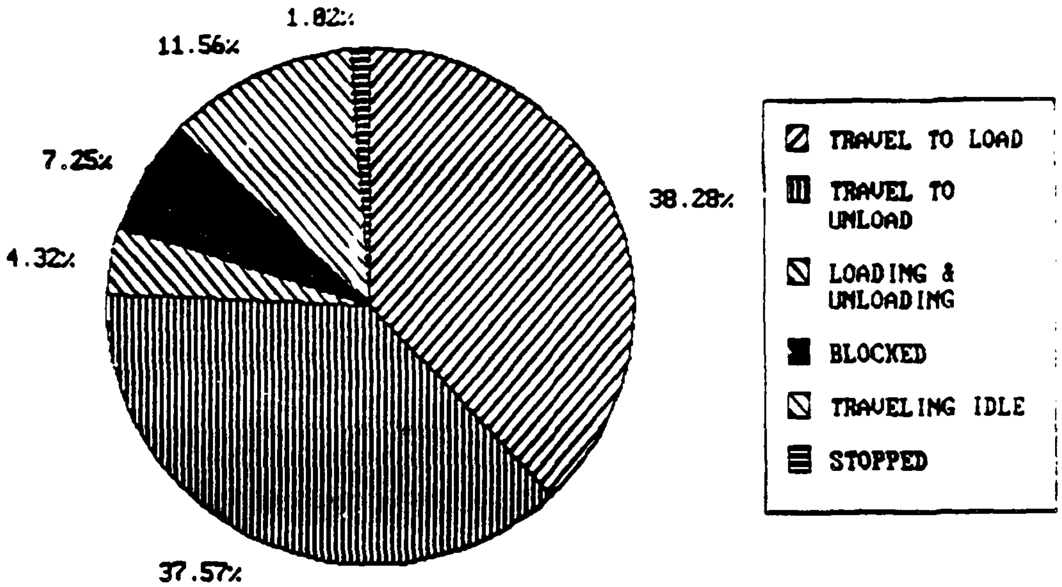


FIGURE 14A AGV UTILIZATION CHART: CASE 5

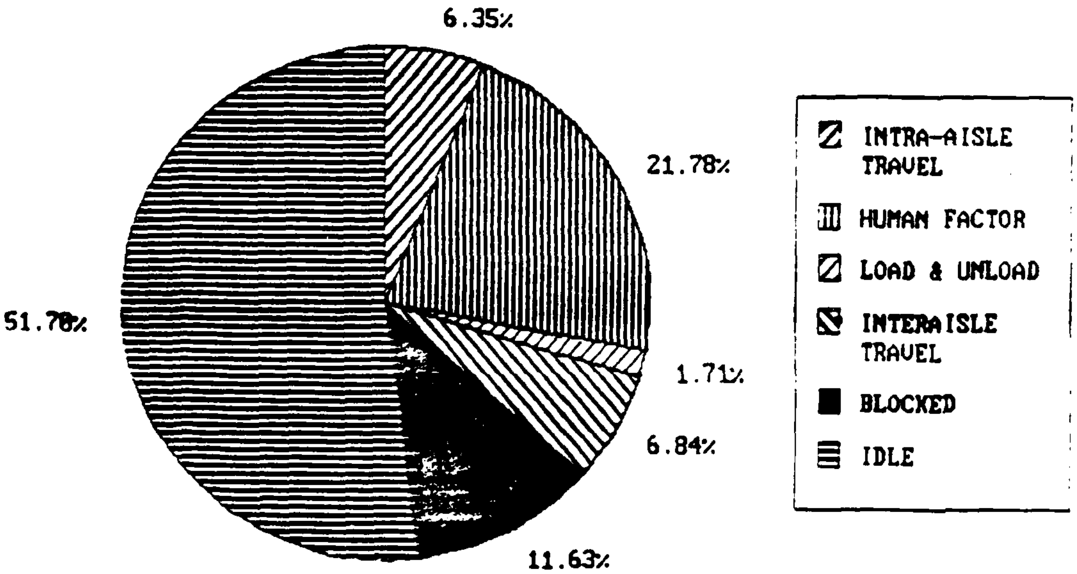


FIGURE 14B S/R UTILIZATION CHART: CASE 5

Case 6

In the final case, the human time standards were reduced significantly. The manual method of completing pick/stow documents was replaced by a computer assisted system. CRT, keyboards, bar code readers, and printers were installed on the S/R machines. A work measurement study indicated that the human time standards:

storing (XX (42)) = 2.74 min/line item
retrieving (XX (43)) = 2.16 min/line item

As a result of the new standards, the material flowed through the system at a much faster rate. The AGV utilization (Figure 15A) increased to eighty percent of their total time. The S/R (Figure 15B) machines however experienced some difficulties. Even though the S/R machine were idle fifty two percent of the time, the units were blocked nearly twelve percent of the time. The problem may be attributed to bottlenecks downstream. In other words, the AGVs were unable to take away the pallets fast enough or the output stations were insufficient in capacity. The problem may be corrected by reducing the number of S/R machines. Additional computer runs would be required, to determine if this change would be a suitable solution to the problem.

TABLE 21

SLAM Summary Report: Case 6

	Mean Value	Standard Deviation	Min. Value	Maxi. Value	Percent Complete
Red orders	36.9	14.4	12.8	70.8	100
Green " "	86.9	22.1	44.4	142.8	100
White " "	176.4	38.3	98.3	247.6	100
All " "	127.4	65.4	12.8	247.6	100
Stows	387.6	52.3	297.3	477.6	94

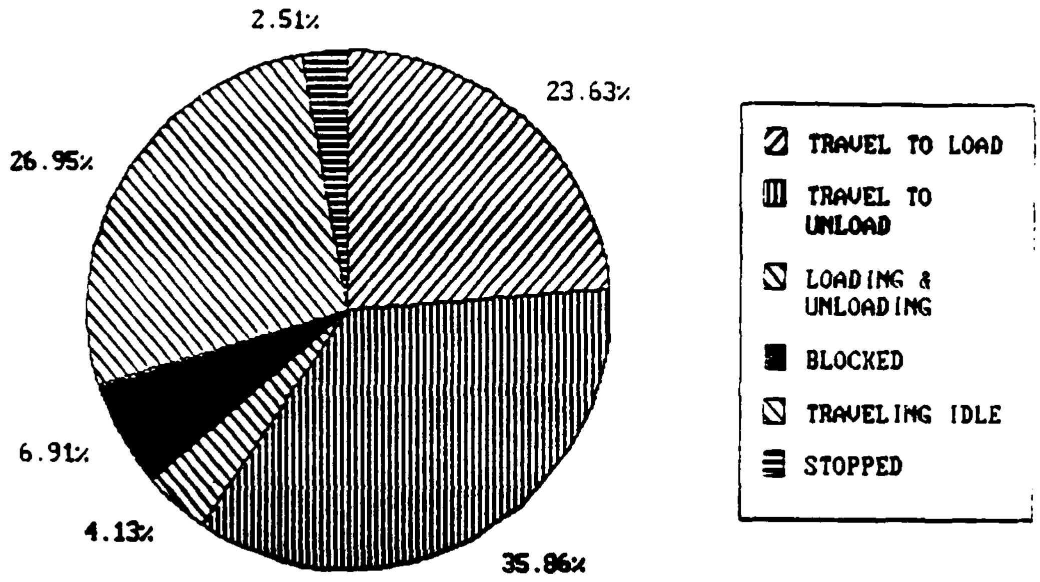


FIGURE 15A AGV UTILIZATION CHART: CASE 6

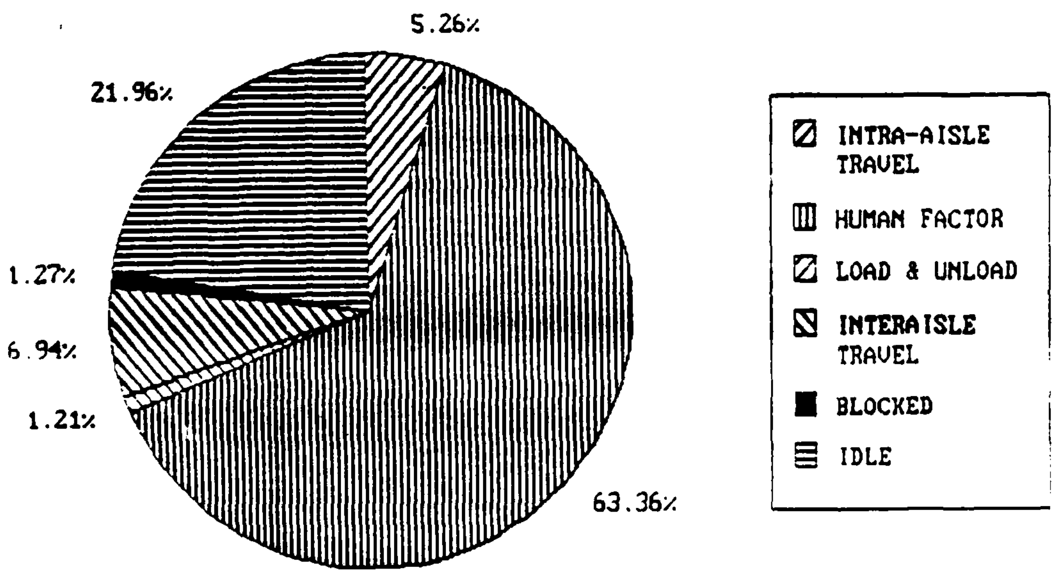


FIGURE 15B S/R UTILIZATION CHART: CASE 6

The results of the six cases presented above are summarized in Table 22. The AGV utilization has been categorized as productive or nonproductive time. The productive time for the AGV may be defined as including the travel time to load, the travel time to unload (less the travel time in loop), the loading time, and the unloading time. The nonproductive time includes the travel time in the loop while loaded, the idle travel time, the time the unit is blocked, and the time it is parked.

The S/R machine utilization has been categorized as productive time, nonproductive time, and human factor time. The productive time for the S/R machine encompasses the travel time within the aisle (intra-aisle), the travel time between aisles, the loading time, and the unloading time. The nonproductive time includes the time the S/R machines are either stopped or blocked. A third category entitled the human factor time has been developed to indicate the amount of time the S/R machine is stationary while the operator is performing a manual pick/stow operation or completing the proper documentation.

The material flow is a reprsentation of the number of traansactions completed (pallets * lot size), divided by the total number of transactions created. The number of transactions did not change in the six cases. These values are provided in Appendix A.

TABLE 22

SUMMARY OF RESULTS	CASE NUMBER					
	1	2	3	4	5	6
AGVs						
TOTAL % PRODUCTIVE TIME	33	51	64	77	63	80
TOTAL % NONPRODUCTIVE TIME	68	49	36	23	38	22
S/R MACHINES						
TOTAL % PRODUCTIVE TIME	7	8	12	13	13	15
TOTAL % NONPRODUCTIVE TIME	59	39	17	28	23	64
TOTAL % HUMAN FACTOR TIME	35	53	71	58	63	22
MATERIAL FLOW (% Orders Completed)						
Red Orders	100	100	100	100	100	100
Green Orders	58	97	100	100	100	100
White Orders	0	20	89	98	99	100
TOTAL	33	55	94	99	99	100
(% Stows Completed)	0	4	47	54	67	84
NUMBER OF TIMES BYPASS LOOP	0	261	12	12	11	0

CASE NUMBER	DESCRIPTION
1	NO LOOP
2	LOOP
3	+ STOWING OPERATIONS BEING AT 11:00 AM
4	+ HUMAN STANDARDS REDUCED BY 20 PERCENT
5	+ NUMBER OF AGVs INCREASED BY 20 PERCENT
6	+ HUMAN TIME STANDARDS FOR A PAPERLESS ENVIRONMENT

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The warehouse simulation model was developed to assist the client in designing one component of a five year modernization plan. The task required that separate models for a storage and retrieval system and a transport system be written and integrated. The model for the storage and retrieval system was written in FORTRAN and simulates an orderpicking (not a unit load) operation. Several unique features were incorporated, including sequencing and batching of orders, variation in the stacking height for each storage level, and movement of S/R machines between aisles.

An AGV transport system model was generated using both FORTRAN functions and SLAM network statements provided in the Material Handling (MH) extension package. The integration of the AGV transport system model and the S/R system model required the use of SLAM II.

The client's overriding concern was to provide customer service. Currently, this concern translates into an operating policy in which the S/R system fills all picking orders before performing any stows. Meanwhile, the AGV system can pick up material for storage whenever it arrives at the receiving terminal of the warehouse. The simulation of this policy, described in Case 1, indicated that both systems would experience total 'lockup' and fail as all input and output queues became saturated and movement was impossible.

A suggested change to the model was the addition of a loop onto which loaded and blocked AGVs were diverted (Case 2). Although the system operated more smoothly, the S/R system still experienced excessive blockage and the AGVs spent a large percentage of their operating time travelling the loop. By preventing the AGVs from picking up material to be stowed until four and one half hours after the start of the shift (Case 3), the effective utilization of the S/R equipment was increased to more than seventy five percent.

Other scenarios tested included the improvement of human performance standards by 20% (Case 4) and the use of standards for a paperless environment (Case 6). In both of these situations, the AGVs were productive more than seventy-five percent of the time but the S/R machines began to experience excessive blockage in case 6. In Case 5, four more AGVs were added to the transport system. Although the S/R equipment was more fully utilized in this case, AGV productivity suffered.

One hundred percent utilization of the S/R equipment can never be achieved because of the transient nature of the system. If higher utilization is desired, the client may want to examine the possibility of scheduling multiple or split shifts.

The simulation model and the results of just a few of the hundreds of possible scenarios were presented to the client. It was pointed out that the model would prove useful in several different ways, including but not limited to the following:

1. comparing different equipment proposals

2. testing and debugging of components during construction of the actual warehouse system

3. performing analysis of the system in operation

4. examining other operating strategies.

However, before the model can be fully utilized, accurate estimates on the daily number of transactions must be provided. Also, a detailed study of the appropriate time standards for the proposed person-on-board S/R system should be conducted. This study is especially important since the simulated operation used standards that were developed in 1979 for a fork truck. If the time to perform the manual part of the pick / stow operation remained high, consideration ought to be given to a part-to-man orderpicking system. Currently, the S/R machines are in actual operation (intra-aisle travel, interaisle travel, loading, and unloading) less than fifteen percent of the time. A part-to-man system would increase machine productivity but not necessarily system productivity, since part-to-man usually requires 2 pick transactions. In this case, consideration must be given to an interleaving policy. Major changes such as the one described, would require modifications to the model.

Use of Model

The development and use of the simulation model can assess the performance of the system before it is actually constructed. The measure of performance most often selected is for optimization of cost. Perry, Hoover, and Freeman (31) have developed a design aid process for selecting a cost effective system.

The problem is described in a linear programming framework. The goal or objective function is:

Minimize: Dollar Cost

Other selected performance measures are used as constraints for the model as described below.

Subject to:	Throughput	> C1
	Hours worked / day	> C2
	Hours worked / day	< C3
	Human idle time	< C4
	S/R utilization	> C5
	AGV utilization time	> C6
	Number of AGVs recycled around the LOOP	< C7

where: C1 - C7 are upper or lower bounds established by the client.

Since the model is descriptive in nature, there is no algorithmic way to optimize the above formulation. Perry, et.al, have developed the following heuristic procedure to solve the problem.

First, list the design variables that describe the physical configuration of the system and govern the dynamic movement of the components. Many of these variables are constrained by the available equipment options. The system performance is also more sensitive to some design variables than others. It is the latter point which is the key to cost effective system design.

Second, select the operating policies which are used to control the actions of the system for efficient and effective performance. The operating policies have a significant impact on the overall system performance. Both the design variables and operating policies for the initial simulation run are listed in Appendix A.

Third, estimate the initial number of S/R machines, I/O stations and AGVs required for the design of the CAPS system. Perry, et.al. (31), recommend a simple expected value model that uses "time in system" values obtained from the trace model in Chapter 4. The expected value model yields a design balance for the S/R machines and AGVs. The model does not include I&O stations because one of each is specified per aisle; nor does the simple expected model take into consideration the effects of lotting orders. The model assumes all S/R machines and AGVs are utilized 100% of the time. Obviously, these assumptions are not valid for a real system. However, the initial values do provide a starting point for a detailed simulation. The results of the Perry model for the client problem are listed in Table 23.

TABLE 23

Simple Expected Value Model

System	**Time**	**Transactions**	**Equipment Required**
S/R			
Picks	Not available for public information		
Stows			
Total			
AGVS			
Picks			
Stows			
Total			

Fourth, use the expected number of S/R machines, AGVs, the original design variables and operating policies as input to the detailed stochastic simulation. If the results of the simulation model meet the constraints listed above, the cost of the system is computed.

Fifth, select the design and operating policy variables to be manipulated. The variables are arranged in order of preference by the client. To simplify the problem a limit on the number of design and operating policy variables should be considered.

Sixth, the second iteration requires the manipulation of the next highest client preference design or operating policy variable. A sensitivity analysis is performed on the variable. If the iteration reduces the system cost the variable is manipulated again (if possible) until a minimum system cost is reached. If the manipulated variable does not reduce system cost the variable is not altered. The iterative process is continued until all the selected design and operating policies have been tested. If the constraints listed above can not be satisfied, attention should be focussed on only the more critical ones.

Seventh, additional iterations require knowledge about the system performance-cost ratios for the components and their interaction before definitive statements can be made about the 'best' system. To design a cost effective system a detailed comprehension of design variables, operating policy variables, and their interaction on system performance is required. This approach could be used for the CAPS system.

Discussion on Programming Language

The Material Handling (MH) extension to SLAM II was extremely useful in modeling the AGVS. The control points, segments of the guidepaths, and the AGV specifications were all input as resource blocks. Logic rules were available to handle contentions at intersections, routing of vehicles, directional characteristics of the track segments, job requests, vehicle requests, and idle vehicle disposition.

As noted in Chapter 4, the division of time increments (DTMIN = 0.0125 min.) resulted in an average error of (0.5 + 0.5 + 6.1) / (9.0 + 9.3 + 22.7) = 0.025 or 2.5%. The consistently higher SLAM values, in comparison to the calculated time values, were proportionally related to the number of control points crossed. No adjustments were made to correct the error. However, the bias of the error is used to offset the affects of acceleration and decceleration of the time values.

The MH extension is not suitable for modeling storage and retrieval systems and was not used for that portion of the simulation. The MH extension requires at least one crane to be assigned to each aisle and allows only one unit to be transported at a time. Also, each pickup, dropoff, and storage location must be identified by X and Y coordinates in a resource block. Since the MH extension has a limited number of resource blocks, the number of possible locations would be restricted. Because of these constraints, user written FORTRAN routines provide a better model of the storage and retrieval system.

Another drawback to SLAM II involves two of the more commonly utilized user-written functions in the software: USERF and UMONT. SLAM II will not allow routine changes in the filing operation to take place when either of these functions is used. This limitation made it difficult to take advantage of sorting utilities written in FORTRAN.

SLAM II is inferior in some ways to its offshoot language, SIMAN. Whereas SLAM II requires that all values be entered directly into the network file, SIMAN offers the user the capability to store capacities of resources, distribution parameters, random number seeds and run times in an experimental file for rapid changes in variables. These features allow SIMAN to be more interactive and 'user friendly'.

Recommendations

The current simulation model should be improved in two ways. First, enhancement of the client's understanding of the results of the model executions is needed. An interface or output processor which would automatically produce histograms, bar charts, and trend graphs, and which would store the data in some type of database management system would benefit the client. Animation packages for graphically displaying the model in execution, or which would save the animation file for replay later would assist the client in 'seeing' potential bottlenecks or hangups in the current design.

Another improvement to the model should be to expand the scope of the operating policies under consideration. Areas that could be explored include:

1. storage assignment policies (2 and 3 based class, and SDF)

2. sequential and batch orderpicking systems

3. interleaving S/R procedures

4. job selection for the S/R machine (FCFS and queue selection)

5. vehicle selection scheme for AGVs (random, longest idle time, longest travel time, and least utilized)

6. contention at AGV intersections (FIFO, closest to point, and priority of load)

7. disposition of idle vehicles

8. location and structure of I/O stations

The client may also wish to consider studying the impact of seasonal changes in demands and the impact machine breakdowns would have on the system. More complex changes would involve incorporating other projects from the modernization plan, providing other options for interfacing the AGV and S/R systems (a circular conveyor connecting all input stations and another connecting all output stations), allowing a larger queue buildup, or reducing the number of pickup and dropoff points for the AGVs.

Finally, for future models, a better computer file system might be examined. Such a system may reduce the amount of computer storage required and could lead to increased execution time.

Bibliography

1. "A Super Example of Top Factory Automation", Modern Material Handling, September, 1983.

2. Bailey, M., "Computer Aided Design for the Automated Warehouse", 1983 ICAW Proceedings, Institute of Industrial Engineers, 1983, pp. 113-123.

3. Barrett, B. G., "An Empirical Comparison of High-Rise Warehouse Policies for Operator-Controlled Stacker Cranes", Eastman Kodak Company, Rochester, N.Y. May, 1977.

4. Bozer, Y. A., "Travel-Time Models for Automated Storage/Retrieval Systems", Material Handling Research Center, Georgia 30332, Summer 1984, pp. 229-238.

5. Bryant, J., & Ripley B., "Binface Action Feasibility Study Automated Warehousing and Retrieval System", Governmental Report, Alexandria, Va., 1984.

6. Chen, S. P., "Design and Optimize an Automatic Storage and Retrieval System", Research Report, Ohio University, Jan. 1984.

7. Davies, A. L., Gabbard, M. C., and Reinholdt, E. F., "Storing Warehouse Stock for Efficient Selection", Western Electric, Des Peres, Missouri, 1979.

8. Dangelmaier, I. W., "Planning the Front Court Area of a High-Bay Warehouse Using Simulation Techniques", 5th International Conference on Automation in Warehousing, Atlanta, Georgia, Dec. 1983, pp. 23-27.

9. "Electote Equipment", Raymond Corporation, Product Reference Guide.

10. Fitzgerald, K. R., "Ford Unveils a Stunning Example of Integration", Modern Material Handling, June, 1986, pp. 64-67.

11. Fitzgerald, K. R., "Two Exhibitions Show the State-of-the-Art", Modern Materials Handling, March, 1986, pp. 73-75.

12. Grant, F. H., 'Material Flow Simulation Issues', Material Flow, Vol. 3, No. 1-3, Feb. 1986, pp. 85-97.

13. Glenney, N. E., and Mackulak, G. T., 'Modeling and Simulation Provide Key to CIM Implementation Philosophy', Industrial Engineering, May, 1985, pp. 76-94.

14. Graves, C. S., Hausman, W. H., and Schwarz, L. B., 'Storage-Retrieval Interleaving in Automatic Warehousing Systems', Management Science, Vol. 23 No. 9, May 1977, pp. 935-944.

15. Groover, M. P., and Wiginton, J.C., 'CIM and the Flexible Automated Factory of the Future', Industrial Engineering, Jan. 1986, pp. 75-85.

16. Hamada, N., 'Evaluation of Fractional Pallet Control for Large Computer-Controlled Warehouse Systems', Electrical Engineering in Japan, Vol. 96, No. 1, Feb. 1976, pp. 125-133.

17. Harmonosky, C. M. and Sadowski, R. P., 'A Simulation Model And Analysis: Integrating AGV's With Non-Automated Material Handling', Proceedings of the Winter Simulation Conference, 1984, pp. 341-347.

18. Hausman, W. H., Schwarz, L. B., and Graves, S. C., 'Optimal Storage Assignment in Automatic Warehousing Systems', Management Science, Vol. 22 No. 6, Feb. 1976, pp. 629-638.

19. 'Introducing the Transtacker SSR 89', Company Brochure, Raymond Corporation, Greene, New York.

20. Koenig, J., 'Design and Model the Total System', Industrial Engineering, Oct. 1980, pp. 22-27.

21. Knill, B., 'Manufacturing 86: Material Handling is the Key to Integration', Material Handling Engineering, Jan. 1986, pp. 62-64.

22. Law, A. M., & Kelton, W. D., Simulation Modeling and Analysis, McGraw-Hill, Inc., New York, 1982.

23. 'Material Handling Provides the Muscle for Integrated Manufacturing', Material Handling Engineering, Jan. 1986.

24. Maxwell, W. L., and Muckstadt, J.A., "Design of Automatic Guided Vehicle Systems", IIE Transactions, Vol. 14, No. 2, 1982, pp. 114-124.

25. McCracken, Daniel D., Computing for Engineers and Scientists With Fortran 77, John Willey and Sons, Inc., New York, 1985.

26. "Modeling AGV Systems", Vendor Pamphlet, Systems Modeling Corporation, State College, PA, 1985.

27. Newton, D., "Simulation Model Calculates How Many Automated Guided Vehicles are Needed", Industrial Engineering, Feb. 1985, pp. 68-78.

28. Norman, Susan K., "Design of a Simulation Package for Automated Guided Vehicle Systems", Masters Thesis, Ohio University, 1985.

29. "Part-to-Man' Systems", Modern Materials Handling - Warehousing Guidebook, 1986, pp. 26-30.

30. Pegden, C. Dennis, Introduction to SIMAN, Systems Modeling Corporation, 1985.

31. Perry, R. F., Hoover, S. V., and Freeman, D. R., "Design of an Automated Storage/Retrieval System", 1983 ICAW Proceedings, Institute of Industrial Engineers, 1983, pp. 57-63.

32. Pritsker, Alan B., & Pegden, Claude D., Introduction to Simulation SLAM, John Wiley & Sons, Inc., New York, 1979.

33. Proceedings of the Fifth International Conference on Automation in Warehousing, IFS (Publications) Ltd., Atlanta, Georgia, 1983.

34. Rygh, O. B., "Integrating Storage In Manufacturing Systems", 5th International Conference on Automation of Warehousing, Atlanta, Georgia, Dec. 1983, pp. 267-274.

35. Salvendy, G., "Automated Storage and Retrieval Systems", Handbook of Industrial Engineering, John Wiley & Sons, Inc., New York, 1982, Chap. 10, Sec. 4, pp. 14-20.

36. Schwind G., 'Automated Storage and Retrieval Plays in a Faster League', Material Handling Engineering, Oct. 1986, pp. 79-84.

37. Sims, R. E. Jr., Planning and Managing Materials Flow, Industrial Education Institute, Boston, Massachusetts, 1968.

38. Spencer, E., 'Integrated Manufacturing: America's Competitive Strategy', Material Handling Engineering, Feb. 1986 pp. IM2-IM32.

39. Takahashi, T., 'Japanese Warehousing Technology Today', 5th International Conference on Automation of Warehousing, Atlanta, Georgia, Dec. 1983, pp. 31-39.

40. 'Using Man-to-Part Picking for Warehouse Efficiency', Modern Material Handling - Warehousing Guidebook, 1986, pp. 21-25.

41. 'Using Simulation to Speed System Decisions', Modern Material Handling, Feb. 1986, pp. 68-70.

42. 'Warehouse Modernization and Layout Planning Guide', NAVSUP Publication 529, March 1985, Part III, Sec. 18, pp. 1-35.

43. White, J. A., and Apple, J. M., 'Material Handling Requirements are Altered Dramatically by CIM Information Links', Industrial Engineering, Feb. 1985, pp. 36-41.

44. White, J. A., and Kinney, H., 'Storage and Warehousing', Handbook of Industrial Engineers, John Wiley & Sons, Inc., 1982. Chapter 10, Sec. 4, pp. 14-21.

45. White, J. A., 'Warehousing in a Changing World', 5th International Conference on Automation in Warehousing, Atlanta, Georgia, Dec. 1983, pp. 3-20.

46. 'Wire Guidance Speeds Orderpicking', Modern Material Handling, Feb. 1986, p. 111.

47. Young, R. E., and Mayer, R. 'The Informantion Dilemma: To Conceptualize Manufacturing as Information Process', Industrial Engineering, Sept. 1984, pp. 28-34.

END
DATE
FILMED
11-88
DTIC